# Transmission systems

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# Transmission systems

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# Outline

- Introduction
- Transmission system components
- Modulation principle
- Analog modulations
  - Amplitude modulations
  - Frequency and phase modulations
- Digital modulations
- Main transceiver architectures

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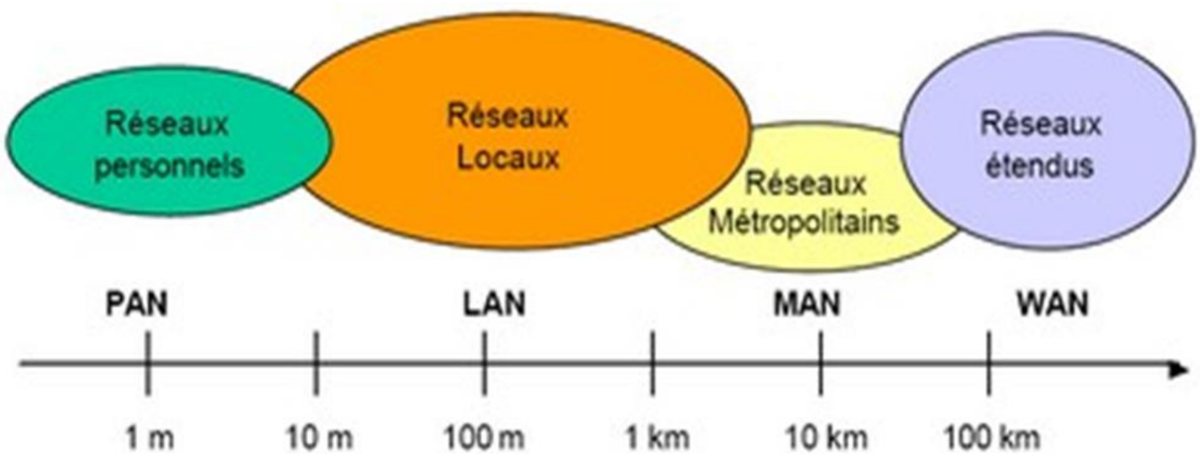
# Introduction

- Course objectives:
  - acquire the basics on
    - Principles of transmission systems
    - Transmission components
    - Transmission technologies and techniques
    - Transceivers architectures
  - Be able to understand, compare and choose a transmission system according to a given application

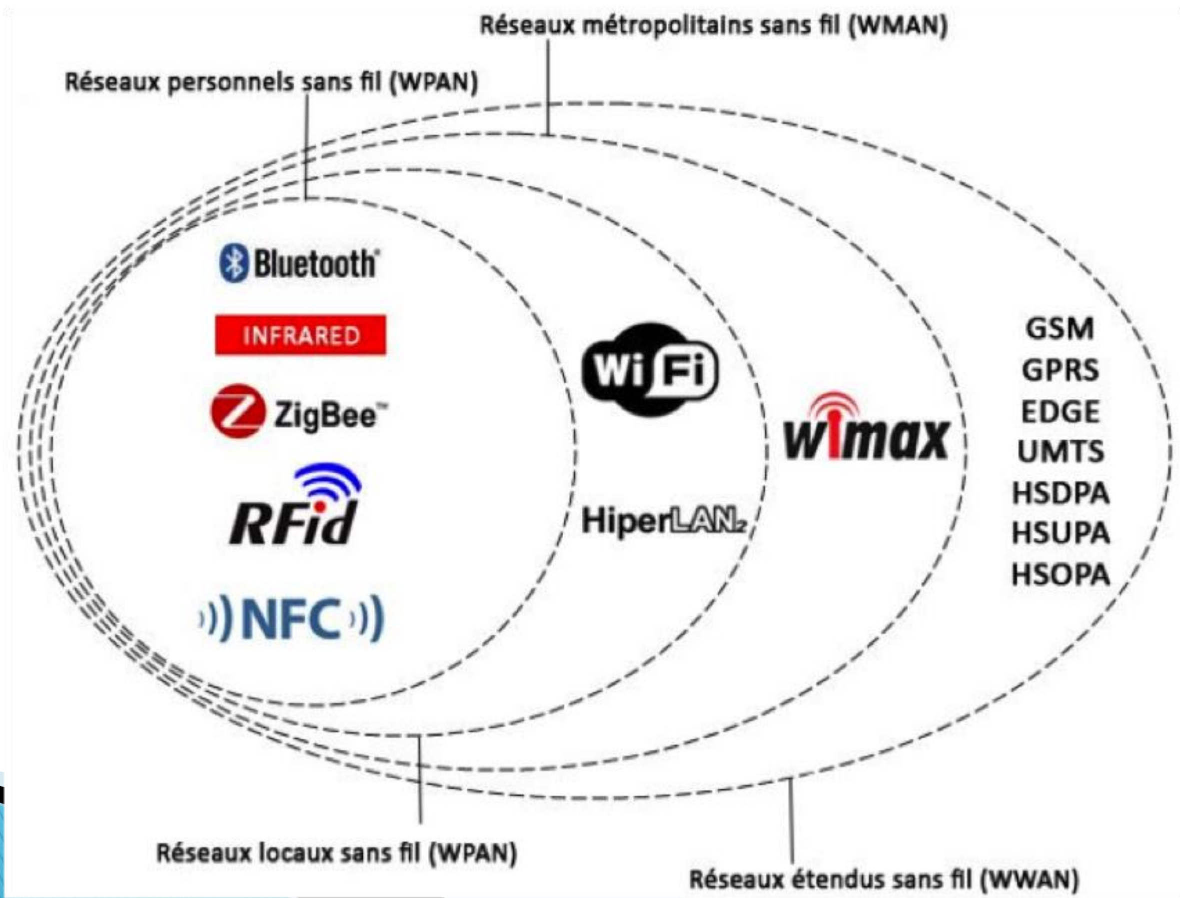
# Introduction

- Transmission systems to share information
  - Through different networks
    - PAN : Personal Area Network
    - LAN : Local Area Network
    - MAN : Metropolitan Area Network
    - WAN : Wide Area Network



# Introduction

- Transmission systems to share information
  - Through different networks wireless or not

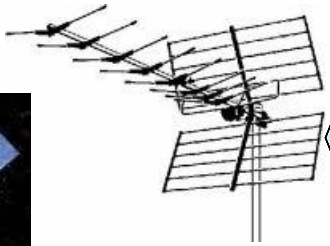


# Introduction

GSM 900 MHz
DCS 1800 MHz
UMTS - LTE 2 GHz

- Classical telecommunications

Analog 800 MHz
DECT ~1900 MHz

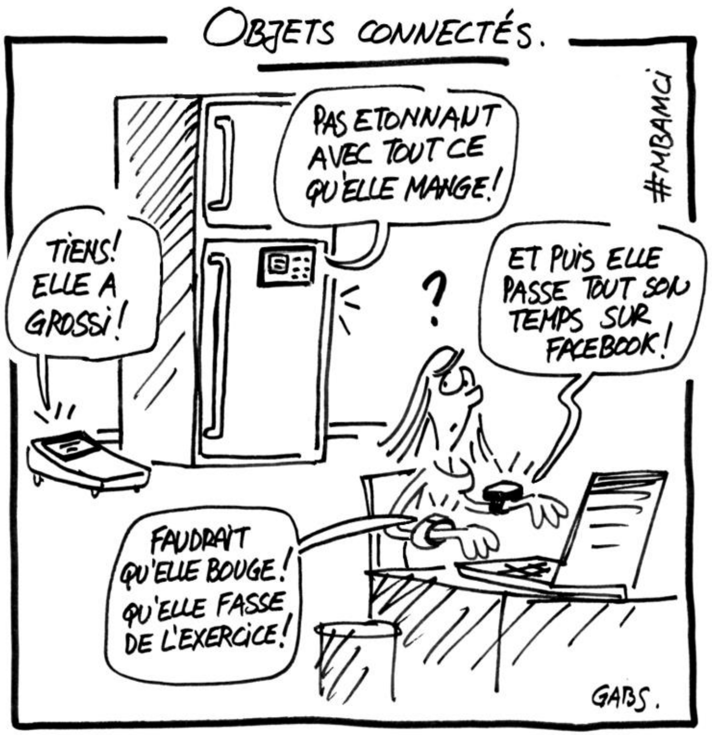


TV terrestre
500 MHz

Satellites 1 à 45 GHz (Ex TV 12 GHz, GPS 1.5 GHz)

# introduction

- Information transmission in an ultra-connected world



# Introduction

- Information transmission in an ultra-connected world
- Ex: transports, smart things

Wifi / Bluetooth / UWB
2.4 - 6 GHz

anticollision radar~80 GHz
Toll ~6 GHz
Garage doors 433 MHz

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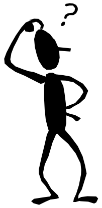
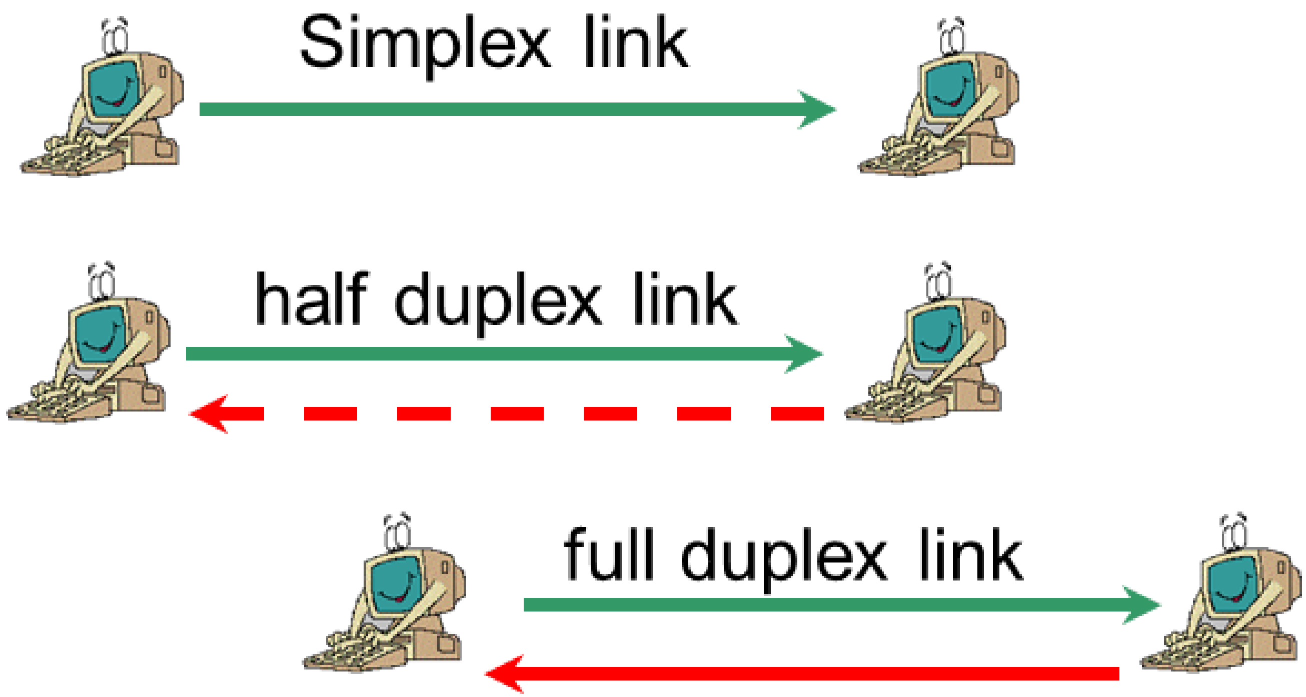
# Transmission system components

- Transmission systems to share information
  - Which kind of information ?
  - Image, sound, temperature, pressure, data
    - Most of them are physical signals (not necessary electromagnetical)
    - Sensors provide electrical signals that vary in an analogous way to the physical variations
    - These variations are continuous in the values and in the time domain
    - Analog signals can be converted into digital ones, then they have discrete or quantized values at discrete instants



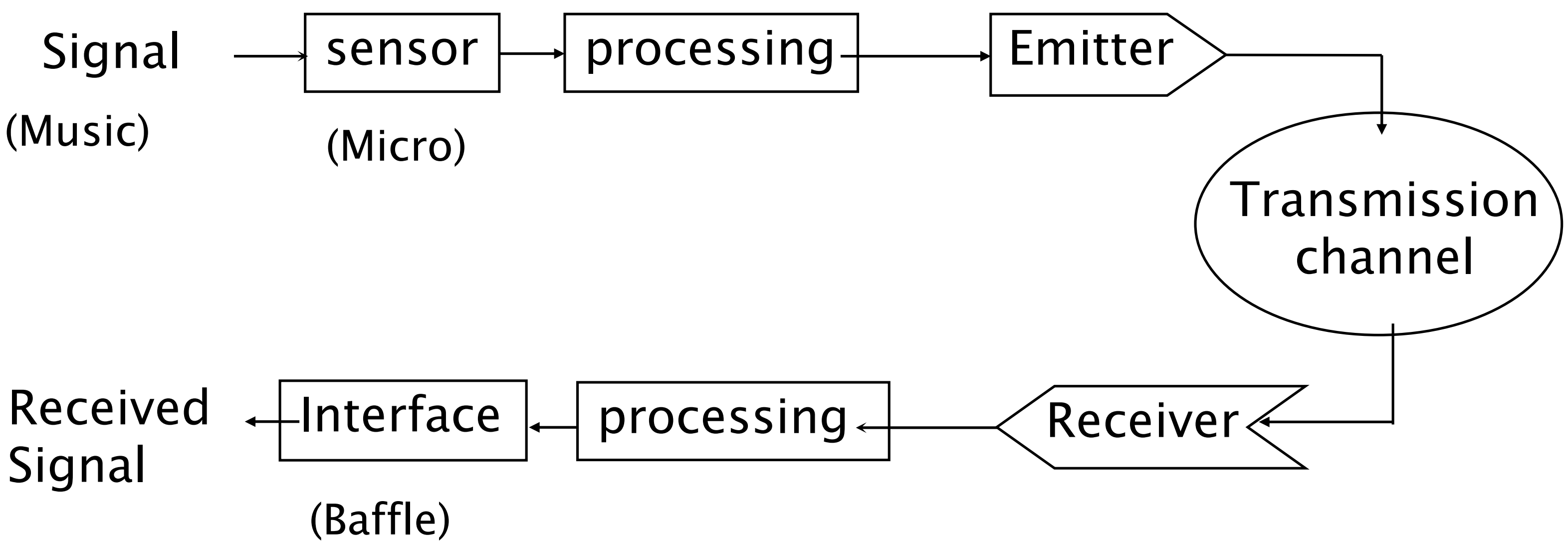
# Transmission system components

- Transmission systems modes



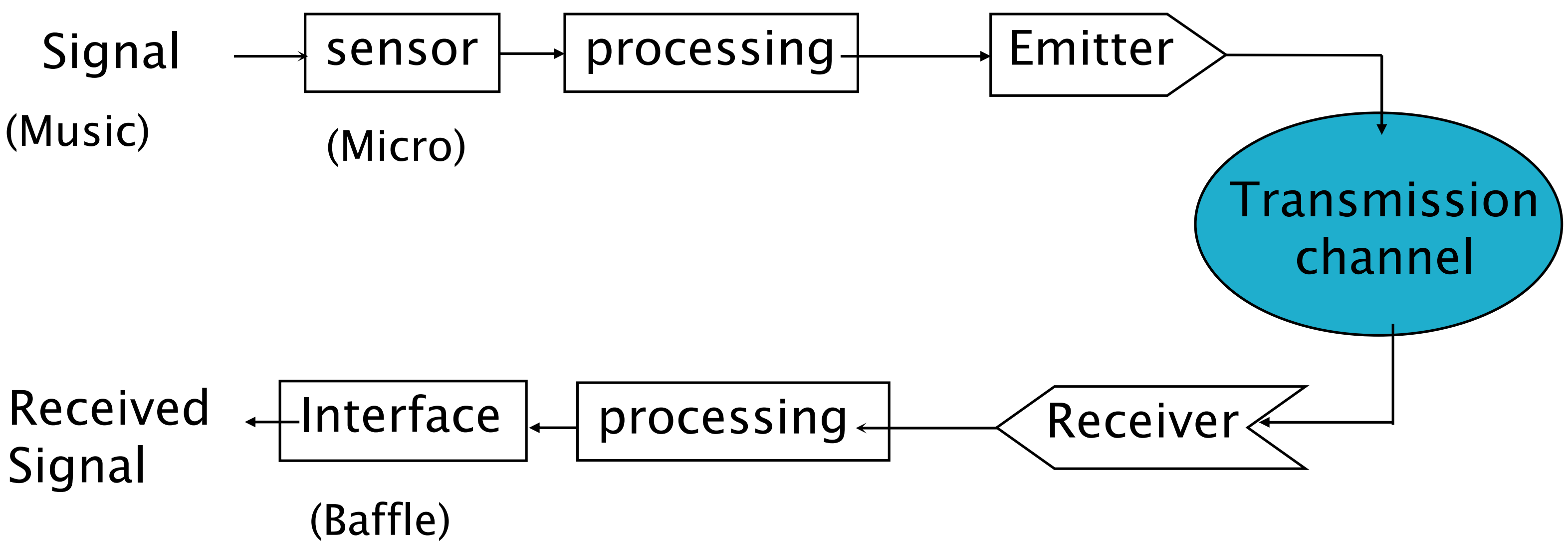
# Transmission system components

- Transmission wired or wireless



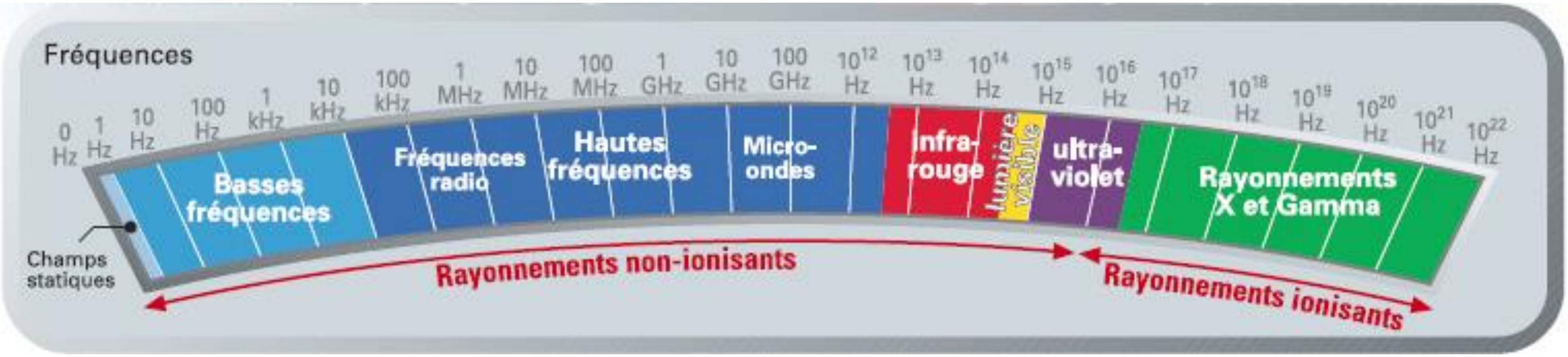
# Transmission system components

- Transmission wired or wireless



# Transmission system components

- Frequency bands

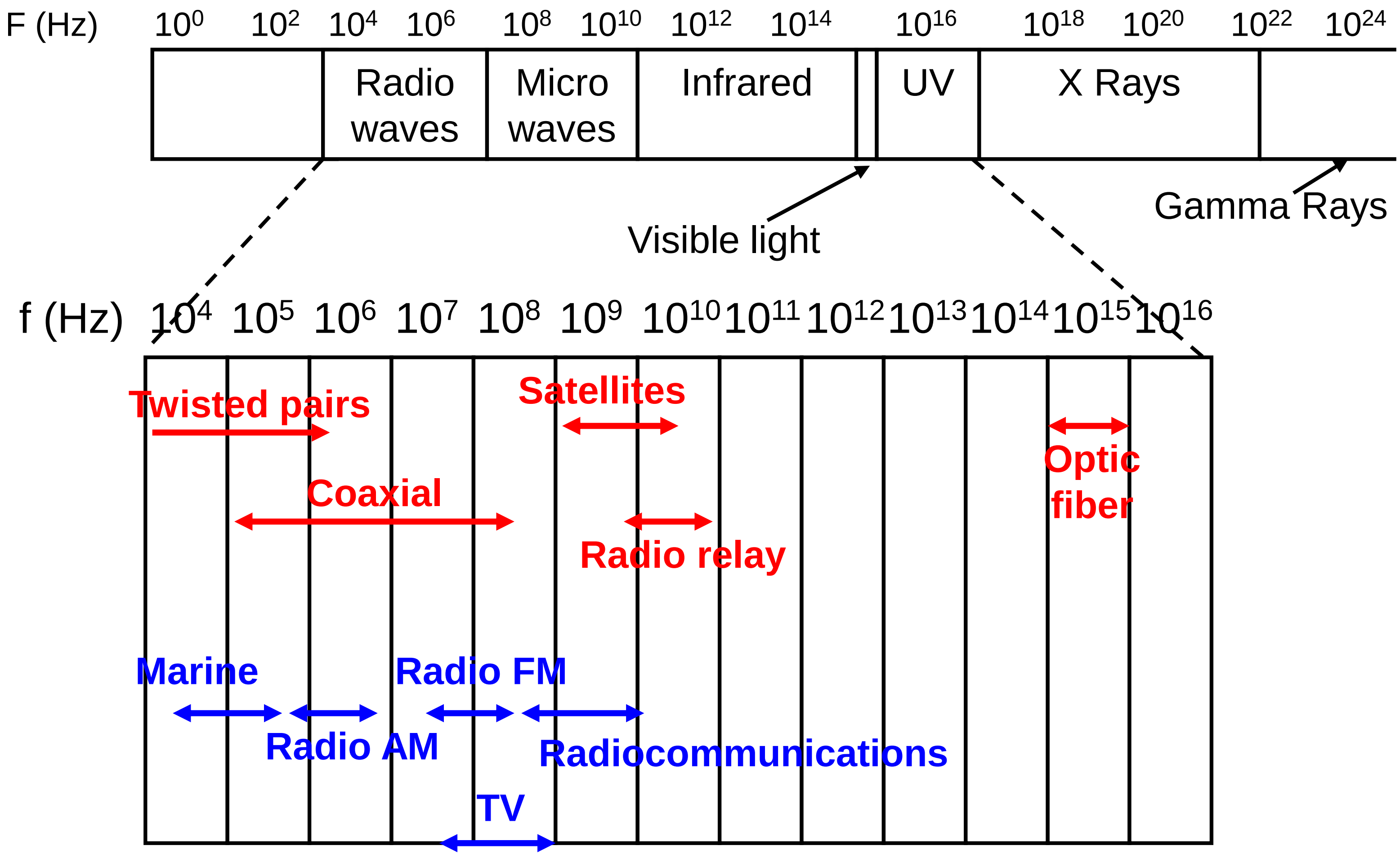



- Transmission channel bandwidth
  - Characterizes any transmission medium, it is the frequency band in which the signals are correctly received

    W = Fmax – Fmin
  - ex: the atmosphere eliminates UV
  - the human ear is sensitive in the band 15-15000 Hz

# Transmission system components

- Transmission channel

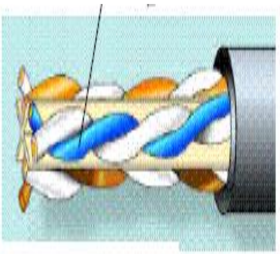


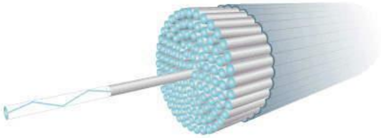

Bandes LF MF HF VHF UHF SHF EHF THF

(Low, Medium, Very, Ultra, Super, Extremely et Tremendously High Frequencies)

# Transmission system components

- Transmission channel
  - Three supports are used in wired networks
    - The twisted pair
    - The coaxial cable
    - The optical fiber



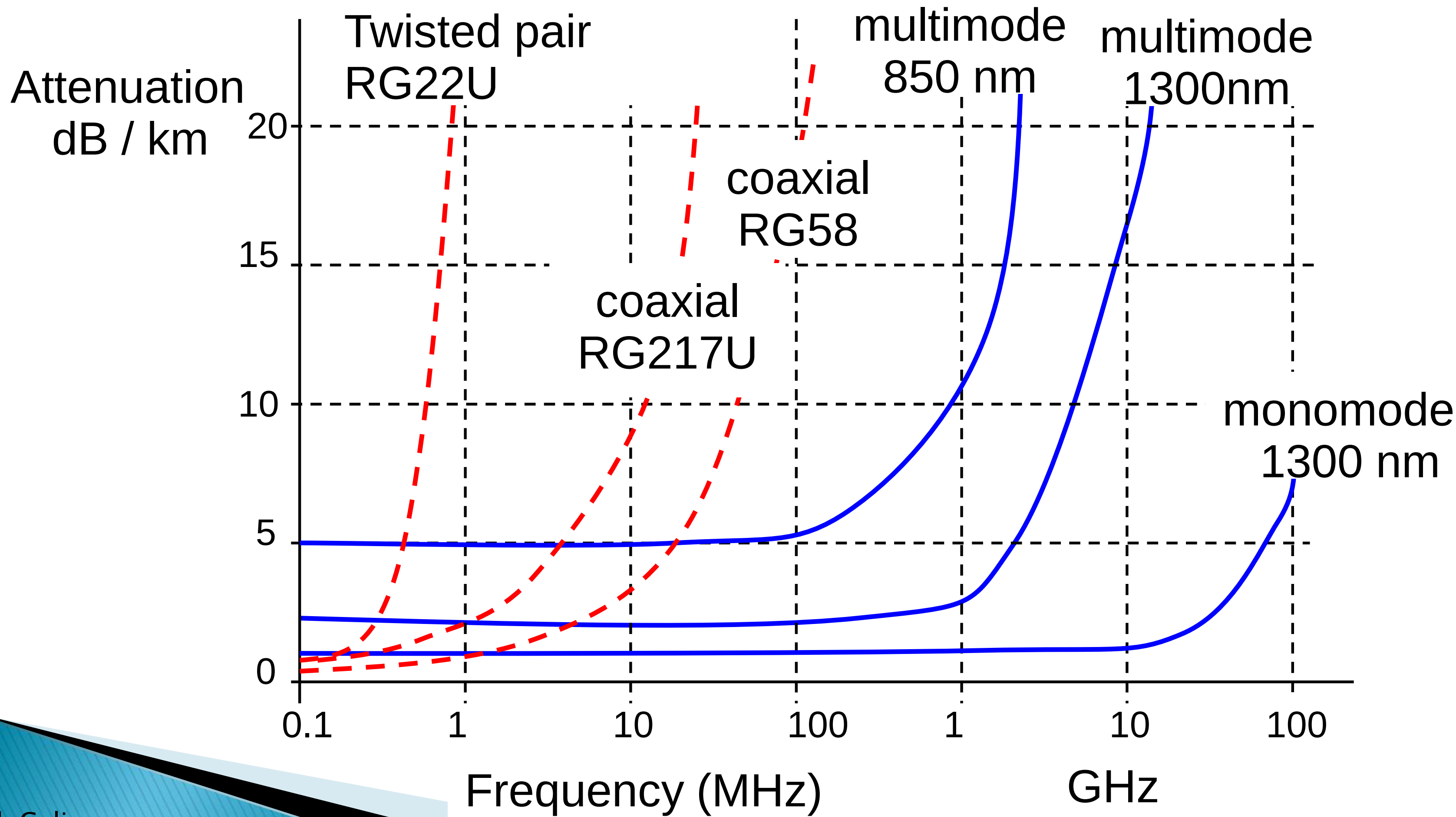


# Transmission system components

- The choice of the medium determines the maximum data rate and the size of the network.
- The choice of a support also determines the wiring conditions
  - Flexibility of support desirable or not
  - Cost of connection
- Transmission channel – Objectives to be achieved in choosing a wiring:
  - high bandwidth,
  - the possibility of using these cables over long distances,
  - easy to install,
  - simple and resistant connectors,
  - low cost ...

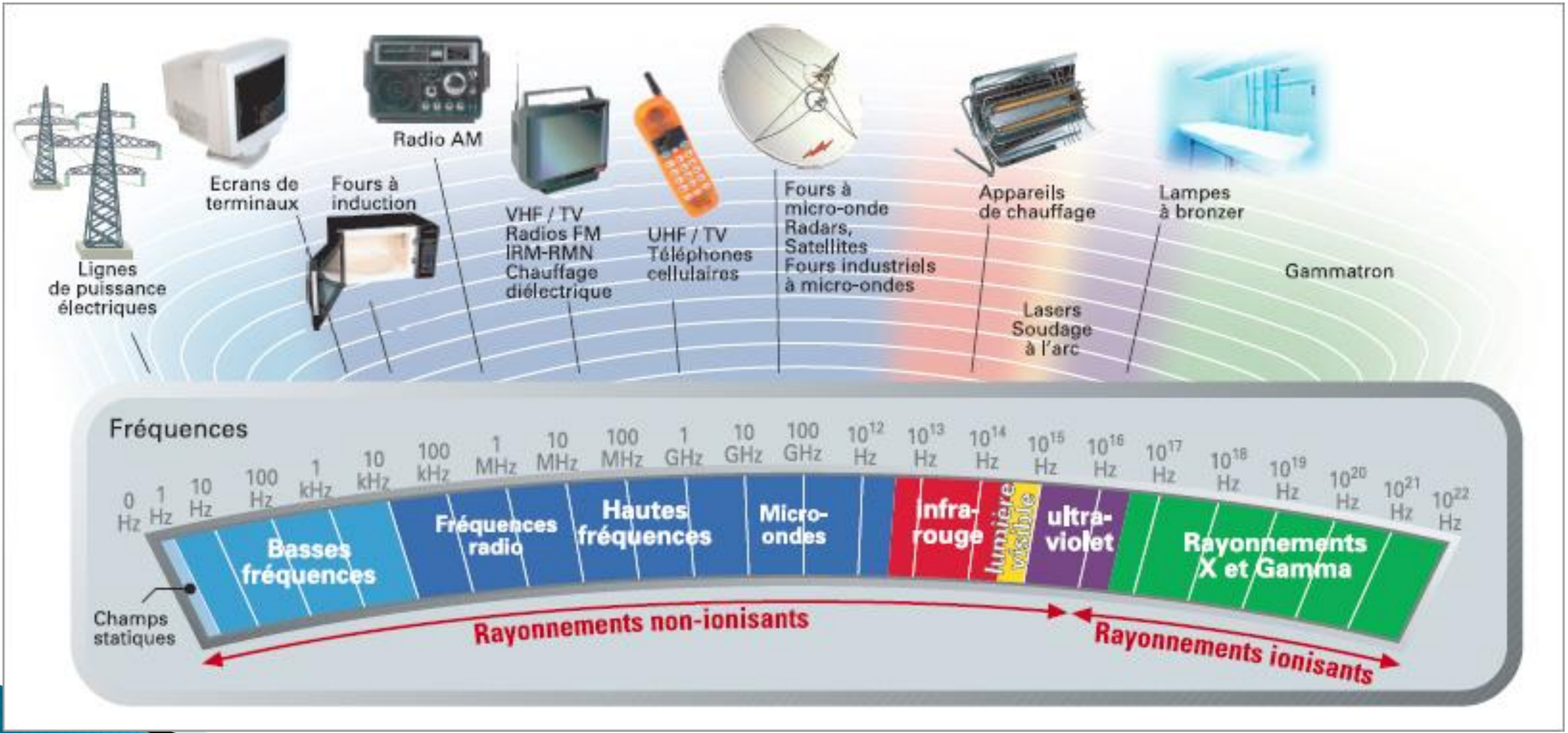
# Transmission system components

- Wired transmission bandwidth



# Transmission system components

- Wireless radiations and transmissions frequency bands



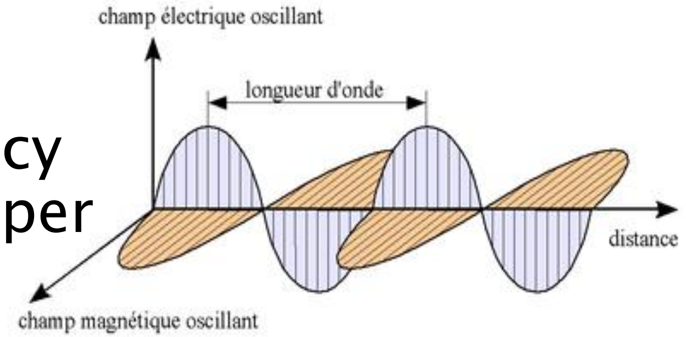
# Transmission system components

- Choice of a frequency band depends on:
  - Desired coverage distances
  - The required data rate
  - The preferred mode of propagation
  - Congestion of the EM spectrum

- Standardization bodies managing the allocation of frequencies:
  - At the international level: the ITU (International Telecommunication Union, http://www.itu.int)
  - At the European level :
  - The ETSI (European Telecommunication Standard Institute, http://www.etsi.org/)
  - The CEPT (European Conference of Posts and Telecommunications, http://www.cept.org/)
  - In France :
  - The ARCEP (former ART, http://www.arcep.com/)
  - The ANFR (National Frequency Agency, http://www.anfr.fr/)

# Transmission system components

- Wired or wireless, the transmitted signal is an electromagnetic wave
  - A wave is a vibration that propagates in space (alternating electric field and magnetic field)
  - A wave is characterized by its frequency expressed in Hertz (number of cycles per second)
  - The frequencies used for mobile and wireless telecommunications are between 900 MHz and 6 GHz
  - Electromagnetic waves propagate in the air at the speed of light (300,000 km / s)



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# Modulation principle

- What is a modulation ?
  - Signal processing which consists on modifying a sinusoidal signal characteristic (amplitude, phase, etc) in order to convey the emitted signal.
  - The sinusoidal modified signal is called the modulated signal
  - The conveyed signal is called the modulating signal.
  - Initial sinusoidal signal is called the carrier $s_c(t)$
  - The emitted signal (modulating) varies or modulates the carrier.

$$s_c(t) = \overbrace{A}^{\text{Amplitude}} \cos\left( \underbrace{2\pi f_0 t + \varphi_0}_{\text{Angle}} \right)$$

# Modulation principle

- Example of an amplitude modulation:
  - Carrier

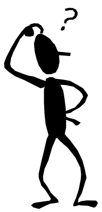
$$s_c(t) = \overbrace{A}^{\text{Amplitude}} \cos\left(\underbrace{2\pi f_0 t + \varphi_0}_{\text{Angle}}\right)$$

  - The amplitude carries the information signal I (t) called the modulating signal: A$\Rightarrow$ A [I (t)].

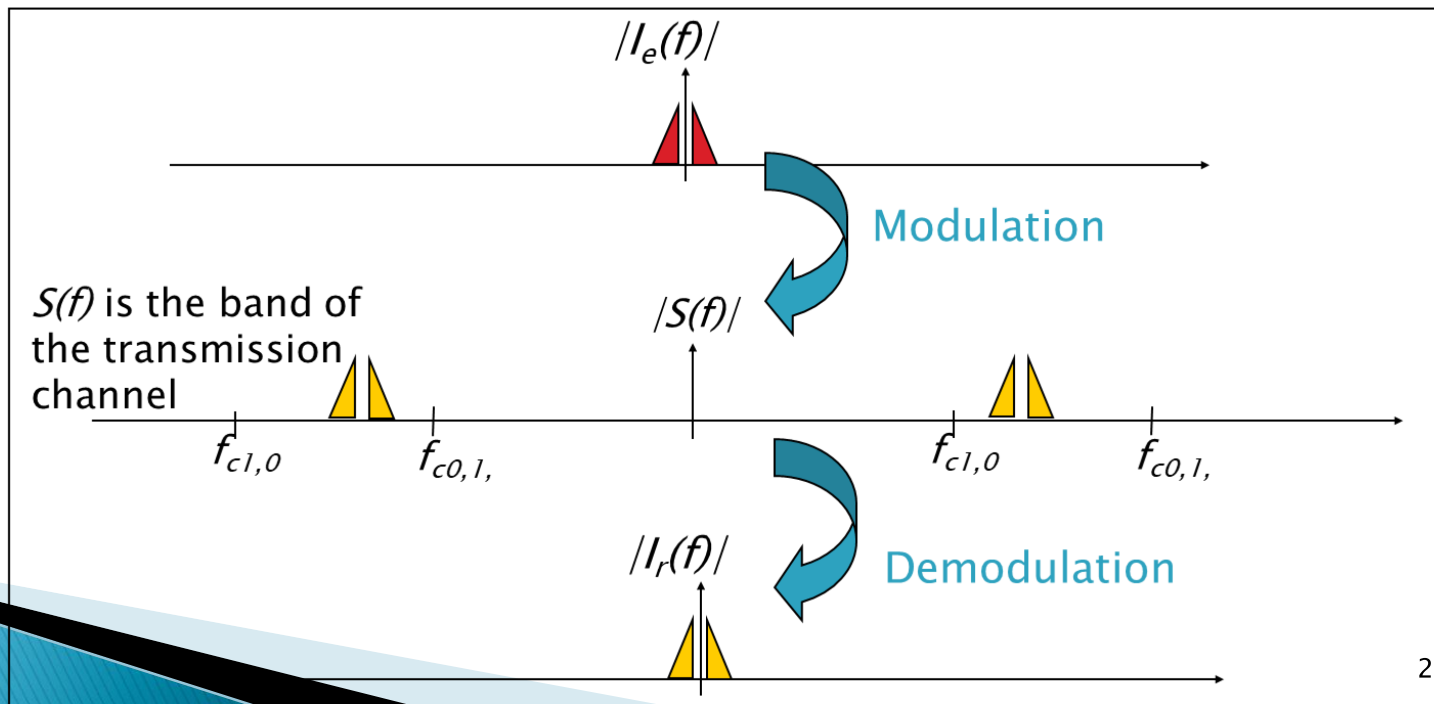
$$s(t) = A[I(t)] \times \cos(\omega_0 t + \varphi_0)$$

  - I(t) : modulating signal
  - s(t): modulated signal

# Modulation principle

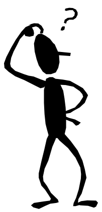


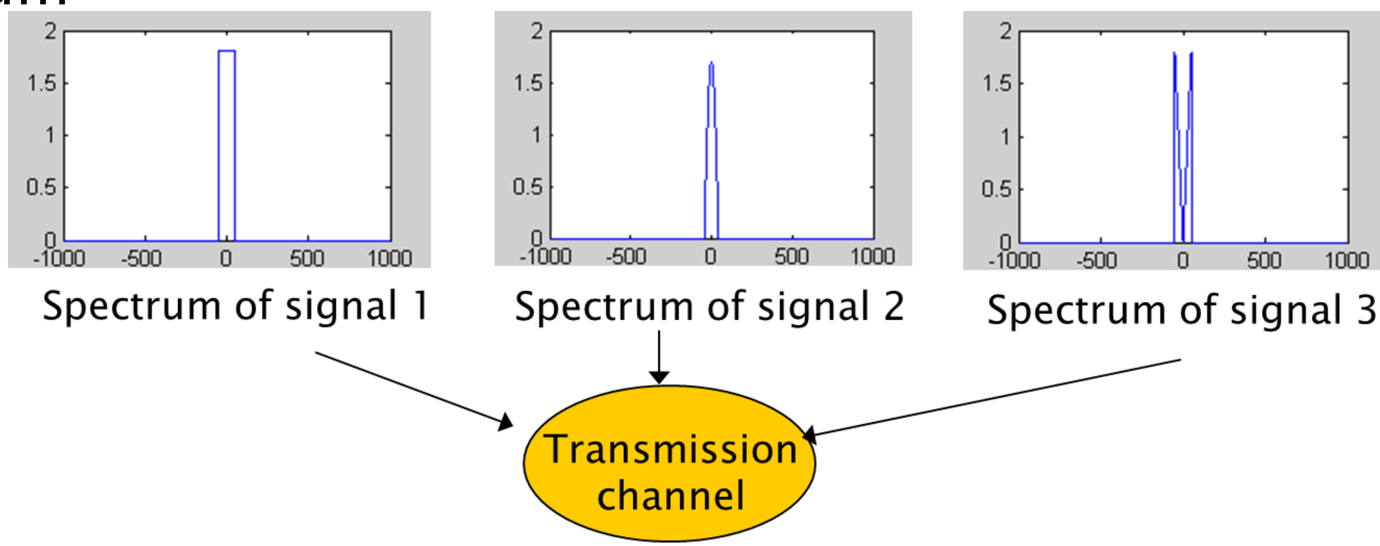
- Why modulate ?
  - Adapt the signal to the transmission channel bandwidth.
    - Frequency translation of the emitted (modulating) signal
    - Small size antennas

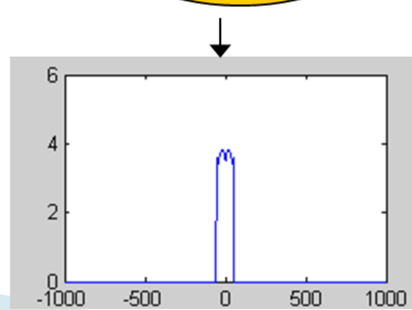


# Modulation principle

- Why modulate ?
  - Multiplex several signals on the same transmission medium



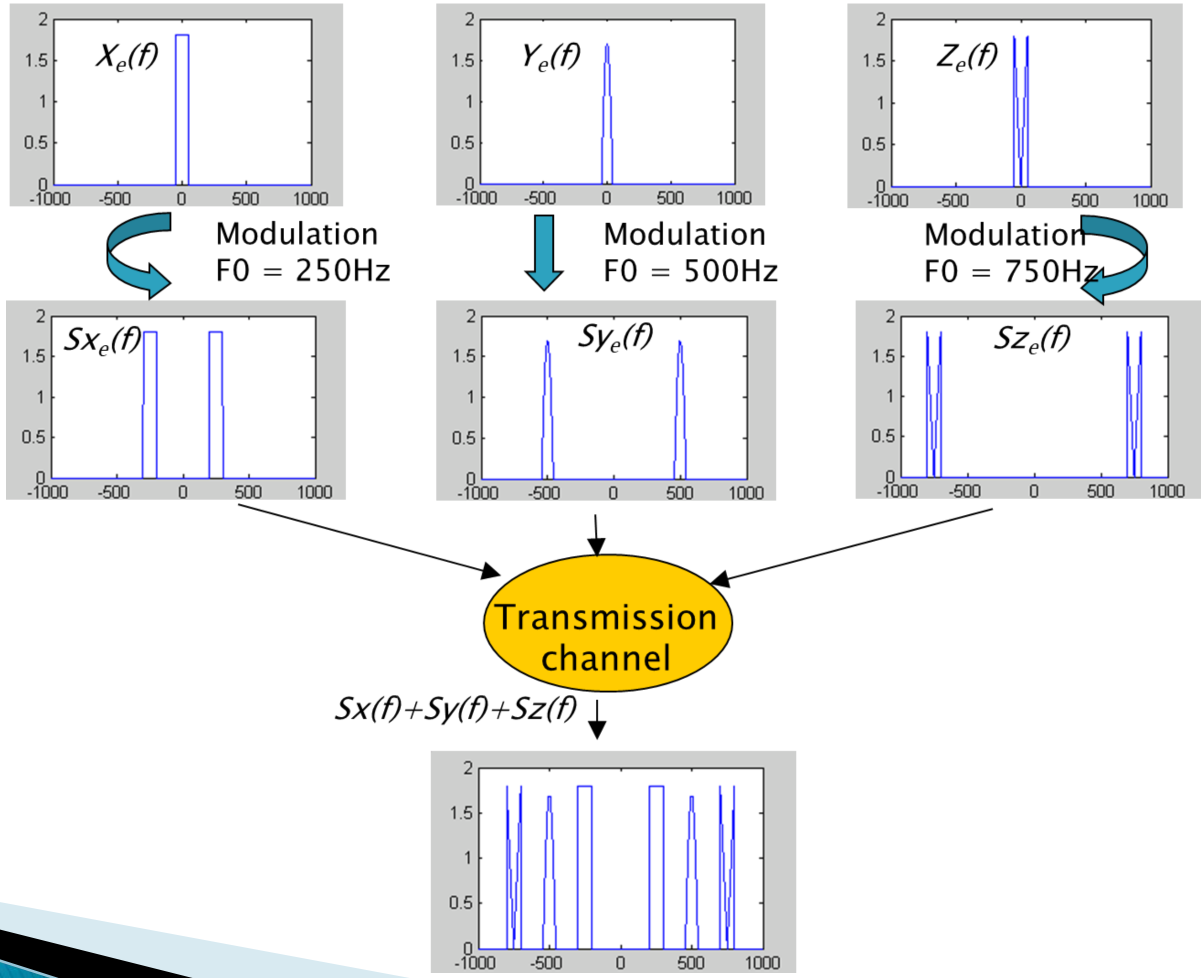


Unable to disassociate the signals at the output of the transmission channel

# Modulation principle

- Why modulate ?



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# Analog Modulations

- **Transmit the information of a signal through a carrier**
- The information is an analog signal: the modulating signal
- The conveyor is a sinusoidal signal: the carrier
- The output is an analog signal: the modulated signal
- The modulating signal can modulate the amplitude, the frequency or the phase of the carrier

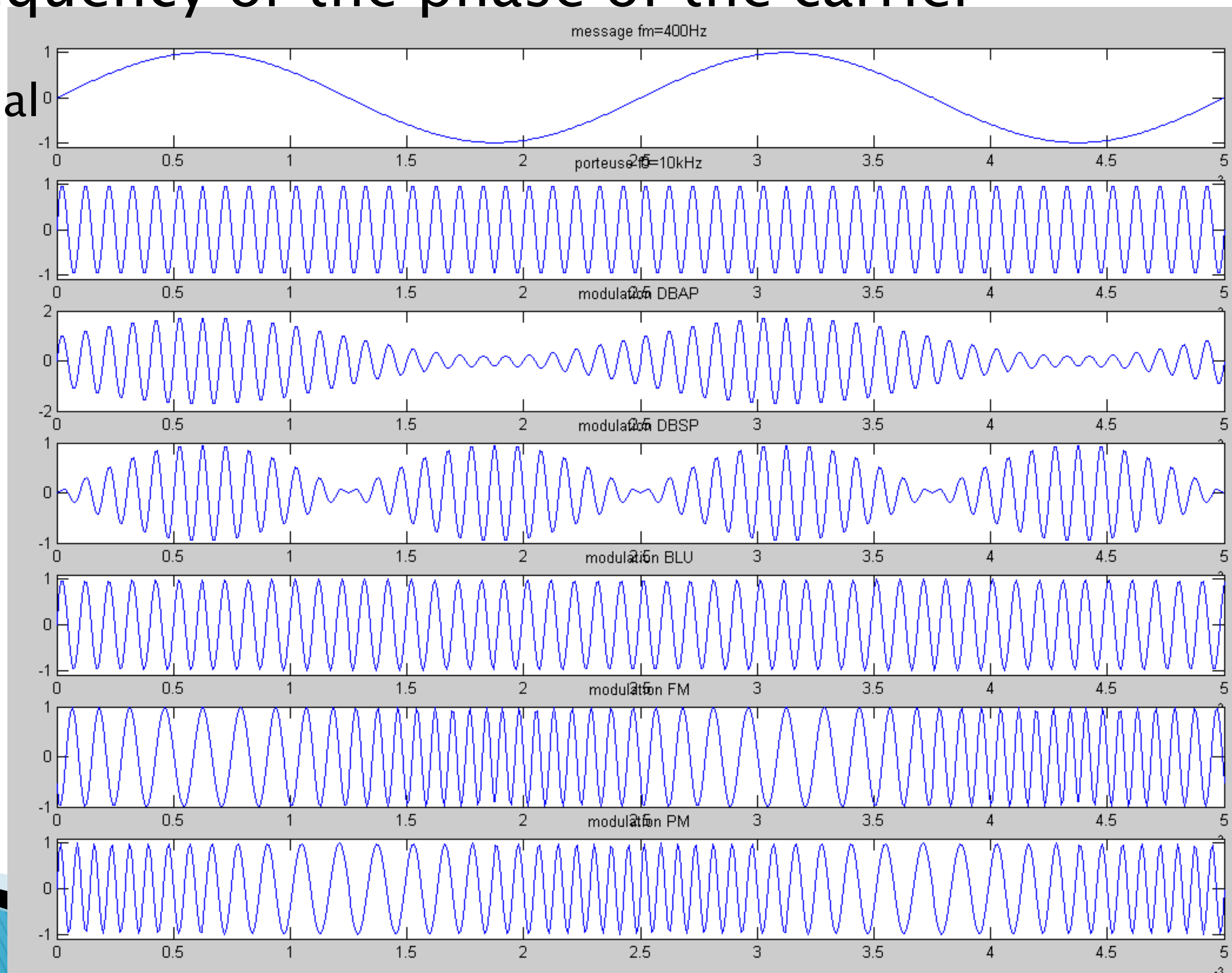
# Analog Modulations

- The modulating signal can modulate the amplitude, the frequency or the phase of the carrier

Modulating signal

carrier

Modulated signals



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# Amplitude Modulation

- The carrier

$$s_c(t) = \overbrace{A}^{\text{Amplitude}} \cos\left(\underbrace{2\pi f_0 t + \varphi_0}_{\text{Angle}}\right)$$

- The amplitude carries the information signal I (t) called the modulating signal:
  - *A ⇒ A [I (t)].*

$$s(t) = A\left[I(t)\right] \times \cos\left(\omega_0 t + \varphi_0\right)$$

  - I(t) : modulating signal
  - s(t): modulated signal

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    - Double-sideband suppressed-carrier (DSB-SC)
    - Double-sideband modulation with carrier (DSB-WC)
    - Single-sideband modulation (SSB, or SSB-AM)
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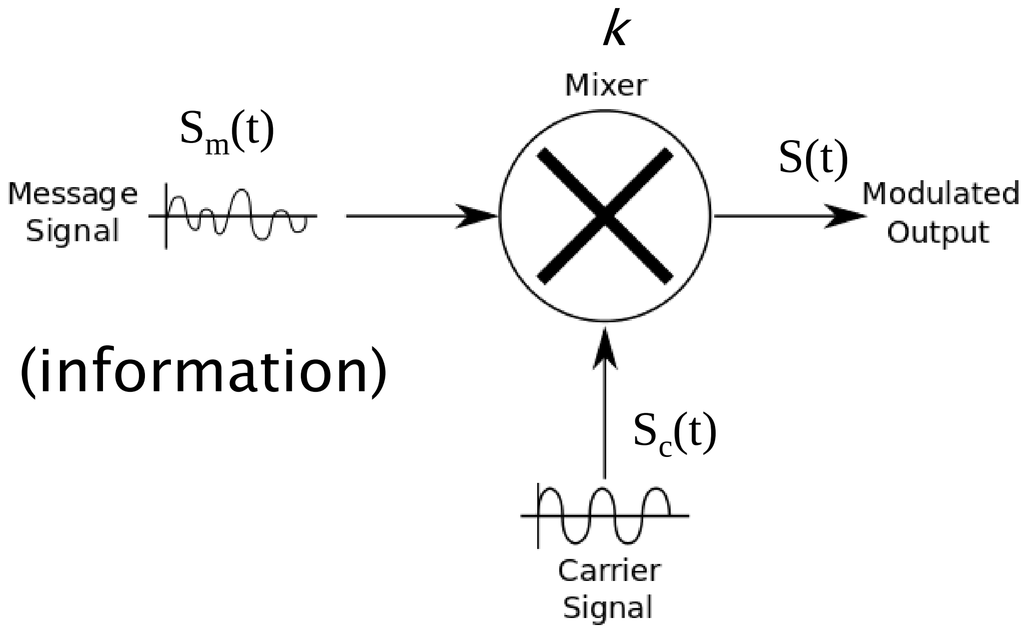
# Double-sideband suppressed-carrier (DSB-SC)

- Modulation




  - Modulating signal (information)

$S_m(t) = A_m cos(2\pi f_m t)$

  - Carrier

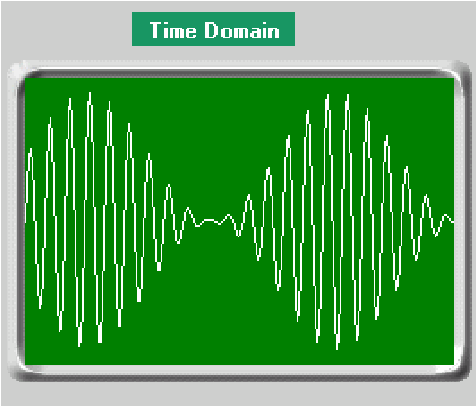
$S_c(t) = A_c cos(2\pi f_c t)$

  - Modulated signal

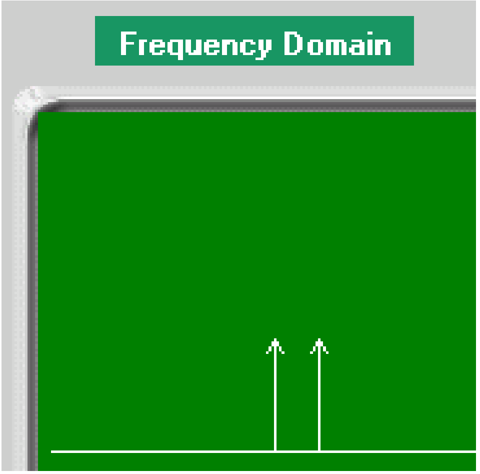
$S(t) = k\, A_m A_c cos(2\pi f_m t)\, cos(2\pi f_c t)$

# Double-sideband suppressed-carrier (DSB-SC)

$$S(t) = k\,A_m A_c \cos(2\pi f_m t)\,\cos((2\pi f_c t)$$

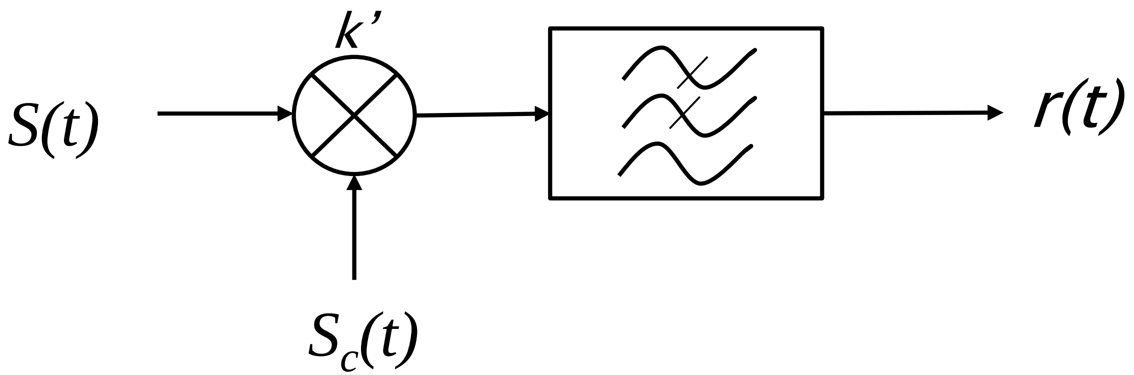



$$S(t) = (k\,A_m A_c/2)[\cos(2\pi(f_c+f_m)t) + \cos(2\pi(f_c-f_m)t)]$$



# Double-sideband suppressed-carrier (DSB-SC)

- Demodulation




Synchronous demodulation

- Carrier

$S_c(t) = A_c cos(2\pi f_c t)$

- Modulated signal

$S(t) = kA_m A_c cos(2\pi f_m t)\ cos(2\pi f_c t)$

# Double-sideband suppressed-carrier (DSB-SC)

- Advantage
  - In conventional amplitude modulation, much of the transmitted power is used to send the carrier
  - The idea of suppressing the carrier so that the power emitted serves only to transmit useful information.

# Double-sideband modulation with carrier (DSB-WC)

- First type of modulation used for radio broadcasting.

- Great simplicity of the receiver .
- Massive use
- Allowed the development of broadcasting in the 1920s.

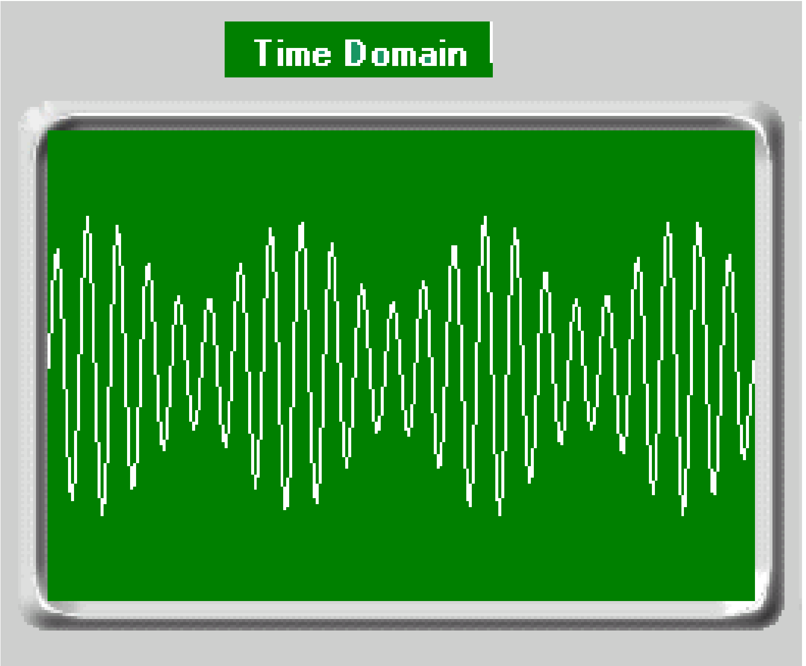
# Double-sideband modulation with carrier (DSB-WC)

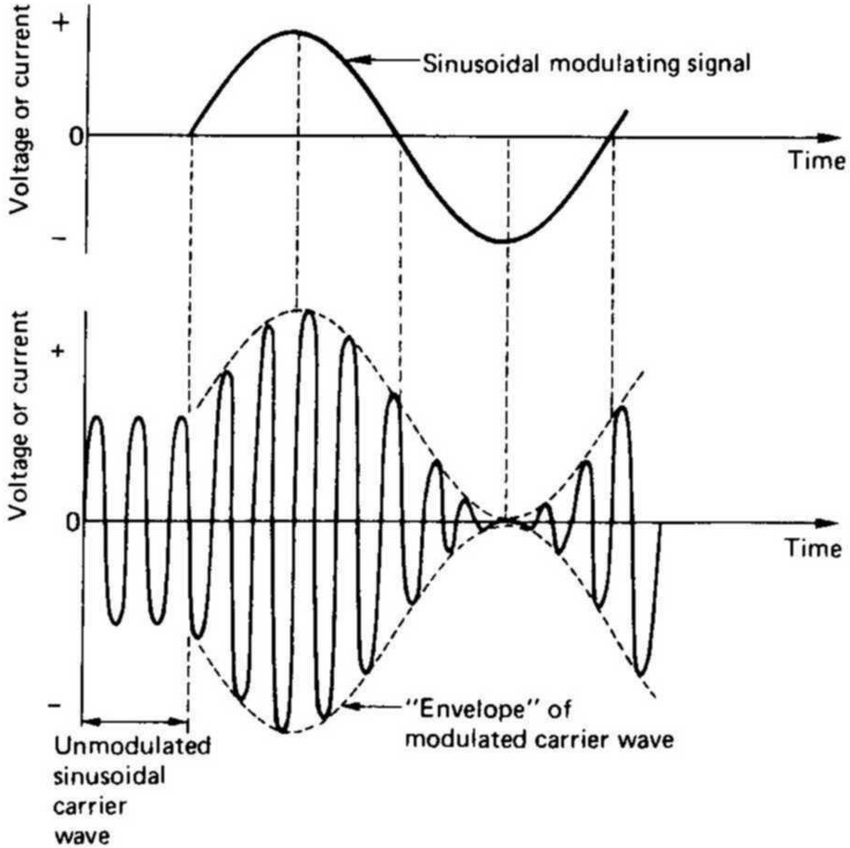
- $S_{DSB-SC}(t) = k\, A_c A_m \cos(2\pi f_c t)\, \cos(2\pi f_m t)$

- To avoid reconstructing the carrier $A_c \cos 2\pi f_c t$ on reception, it is transmitted with the signal produced.
- $m = kA_m$ modulation index (or rate)
- $S(t) = A_c\, [1 + m \cos(2\pi f_m t)]\, \cos(2\pi f_c t)]$.

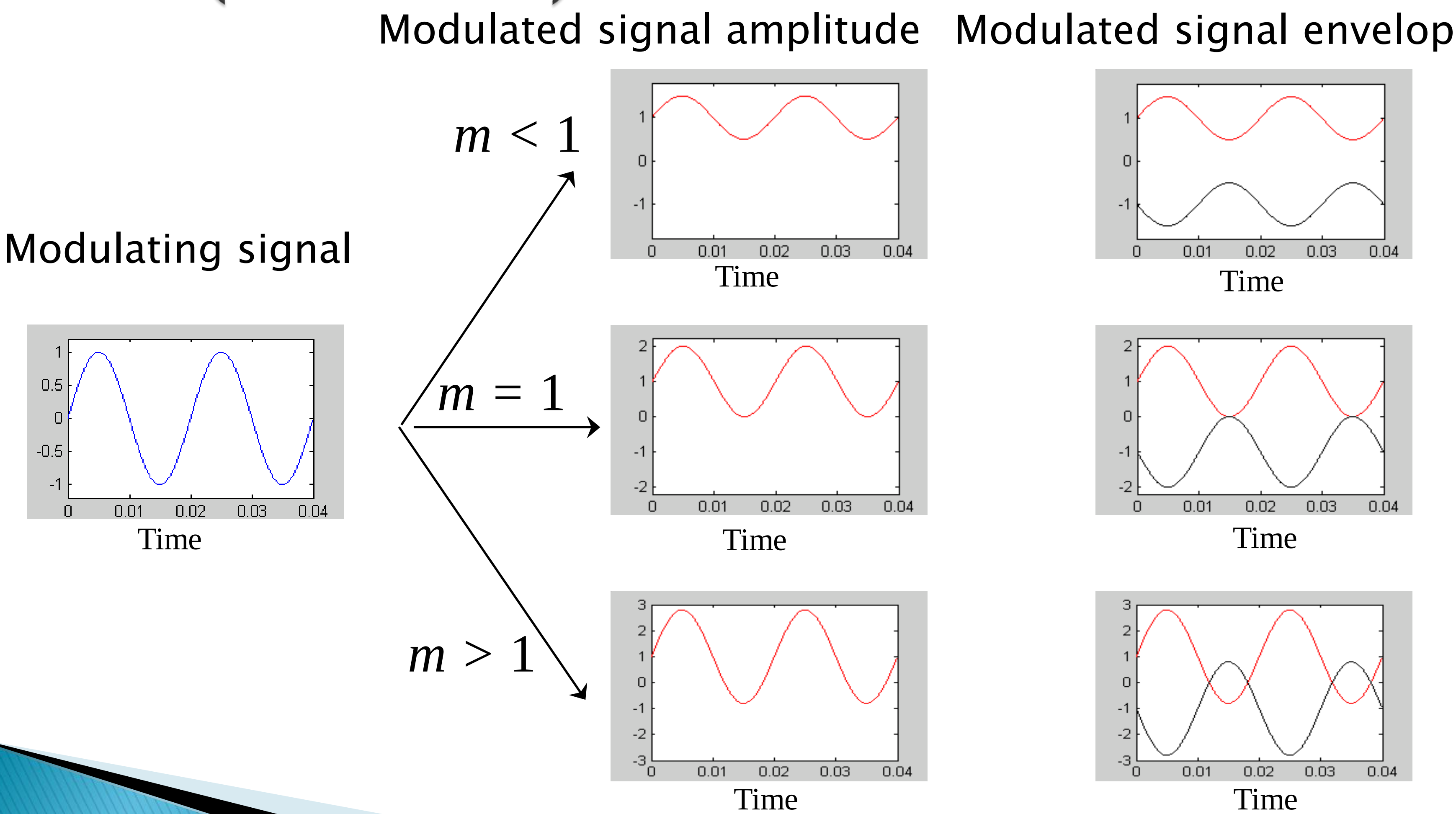
# Double-sideband modulation with carrier (DSB-WC)

- $S(t) = A_c\,[1+m\cos(2\pi f_m t)]\cos(2\pi f_c t)$.



# Double-sideband modulation with carrier (DSB-WC)

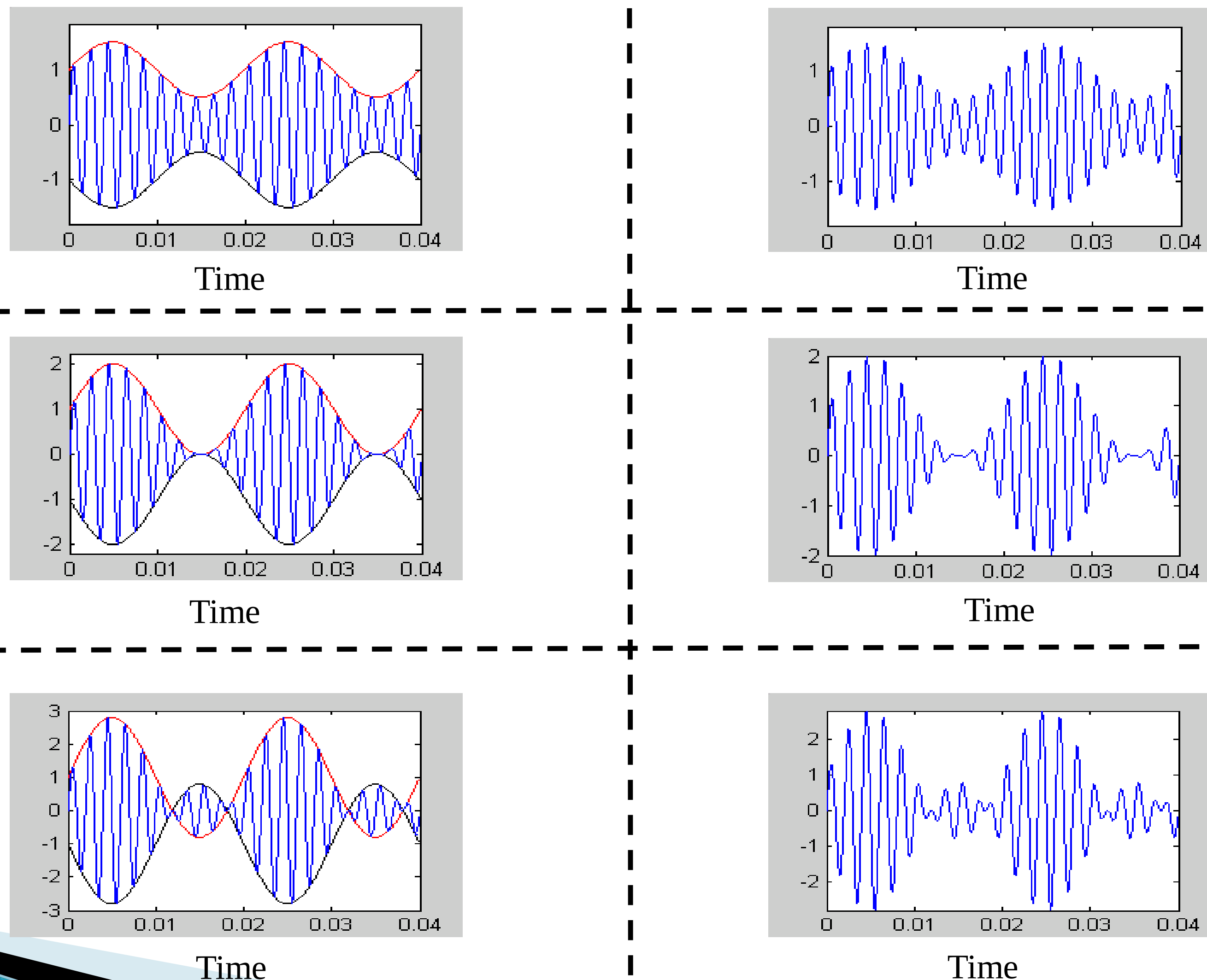


# Double-sideband modulation with carrier (DSB-WC)

$m < 1$

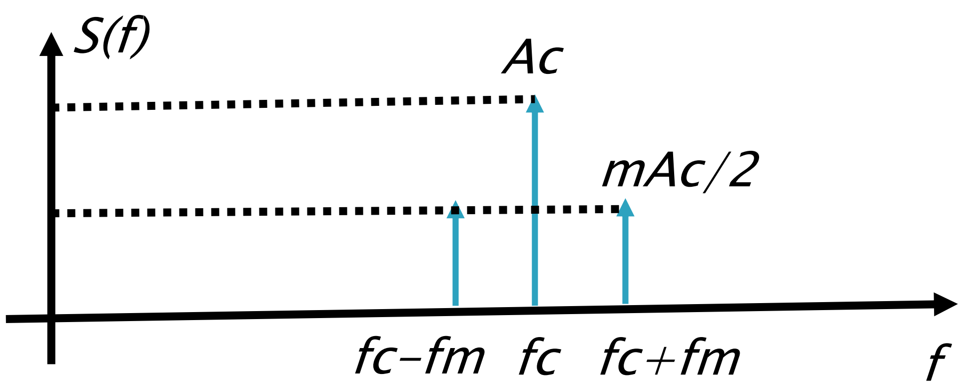
$m = 1$

$m > 1$



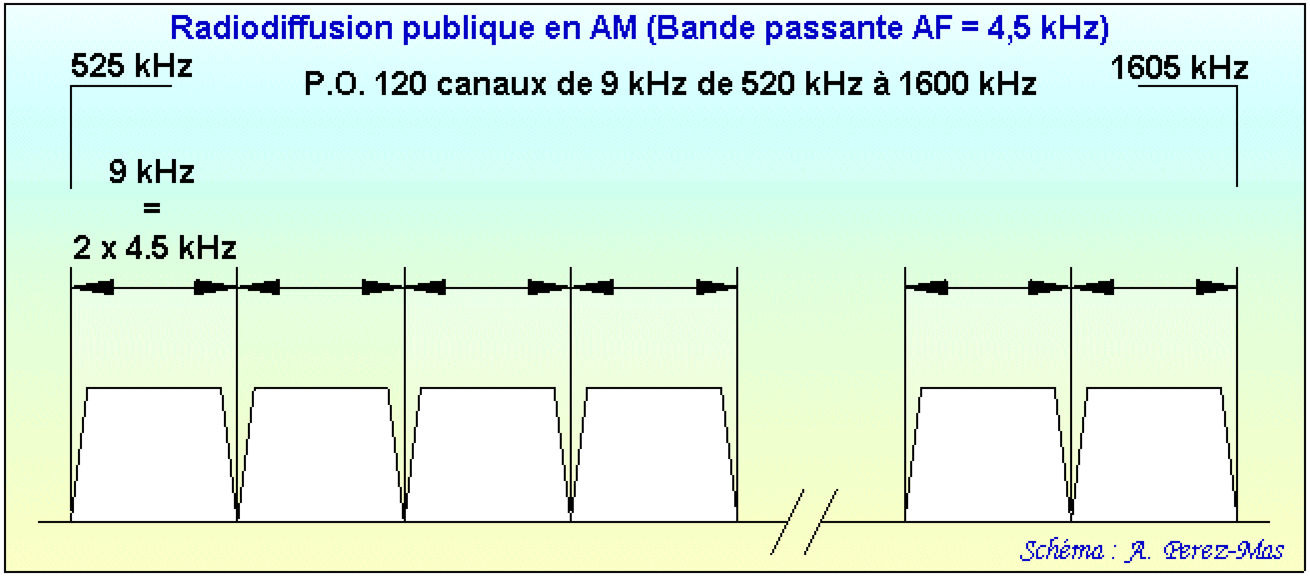
# Double-sideband modulation with carrier (DSB-WC)

- $S(t) = A_c\,[1+m\cos(2\pi f_m t)]\cos(2\pi f_c t)$.
- $S(t) = A_c\cos(2\pi f_c t)+(mA_c/2)[\cos(2\pi(f_c+f_m)t) + \cos(2\pi(f_c-f_m)t)]$.



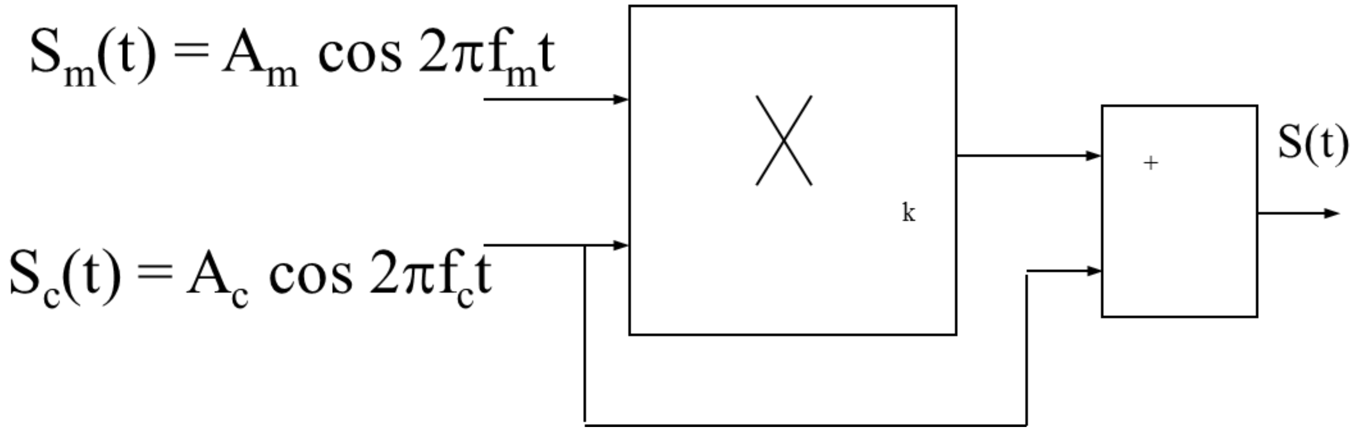
# Double-sideband modulation with carrier (DSB-WC)

- An international standard sets a frequency band of 9 kHz maximum (2 lateral bands of 4.5 kHz) for AM broadcasting stations.
- Thus 120 channels with a width of 525 kHz to 1605 kHz for 120 transmitters



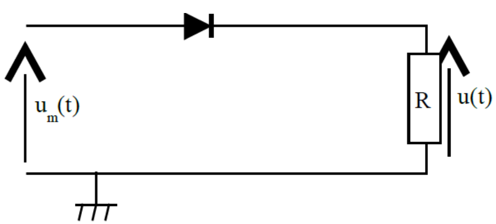
# Double-sideband modulation with carrier (DSB-WC)

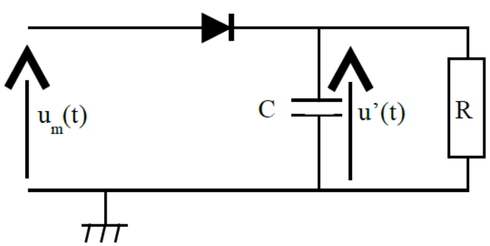
- Modulation

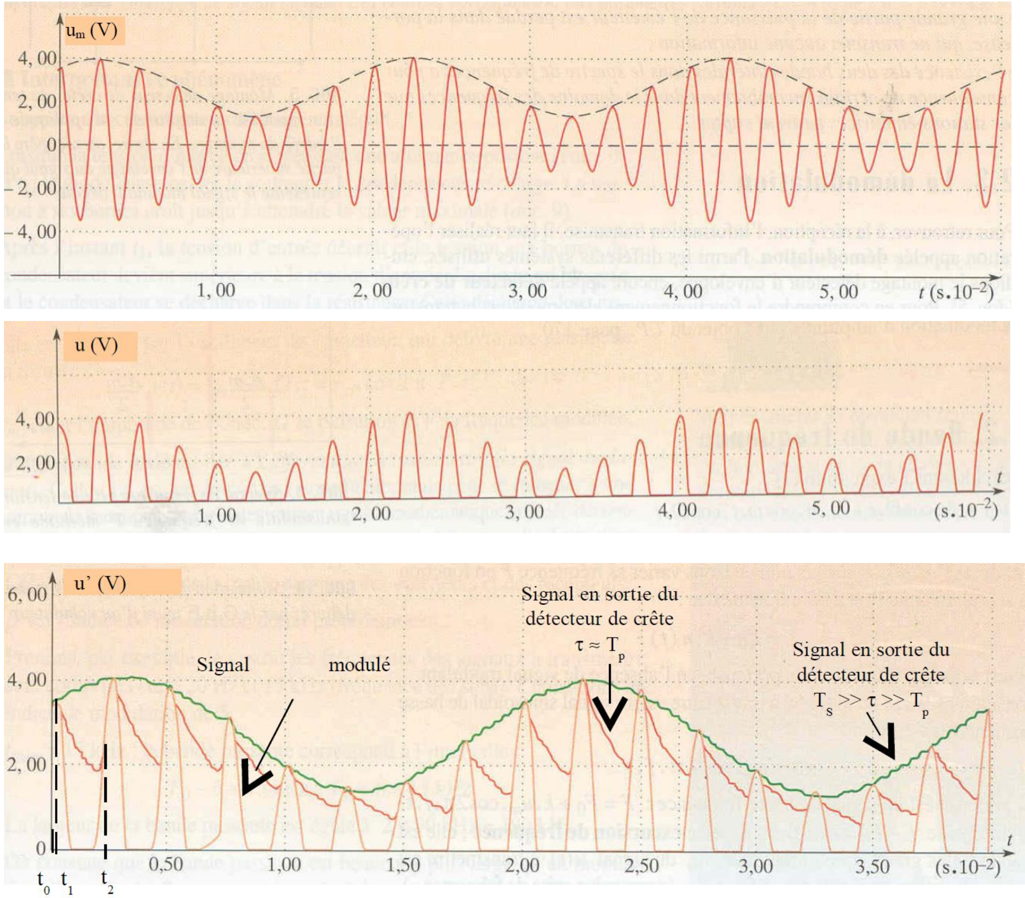


# Double-sideband modulation with carrier (DSB-WC)

- Demodulation : envelop detection

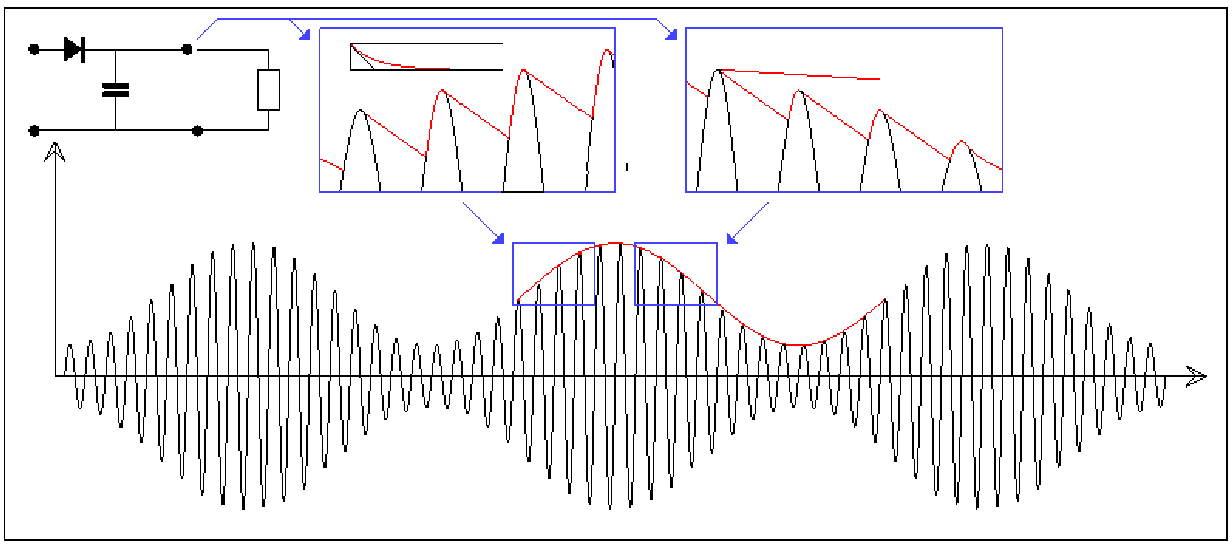


# Double-sideband modulation with carrier (DSB-WC)

- Constant time calculation



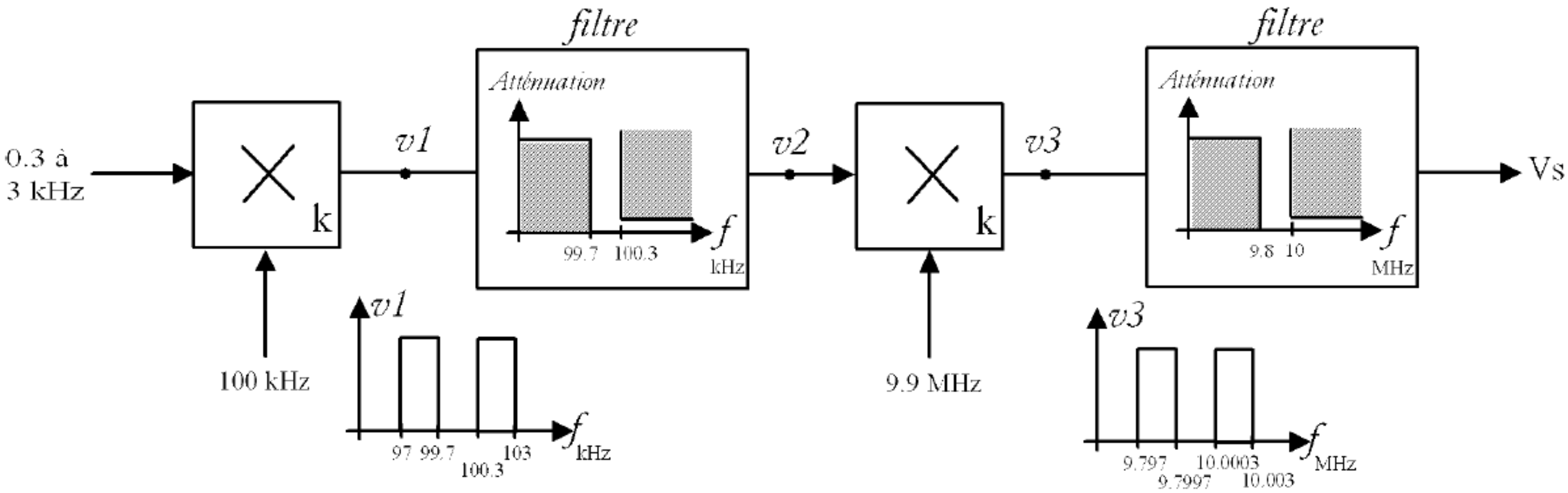
# Single-sideband modulation (SSB, or SSB-AM)

- Improve spectral efficacity -> useful information is a small part of the emitted signal
- Oversize the output power stages of the transmitters.
- Keep a single band before emission

- $S(t) = \frac{kA_cA_m}{2}\cos(2\pi(f_c + f_m)t)$

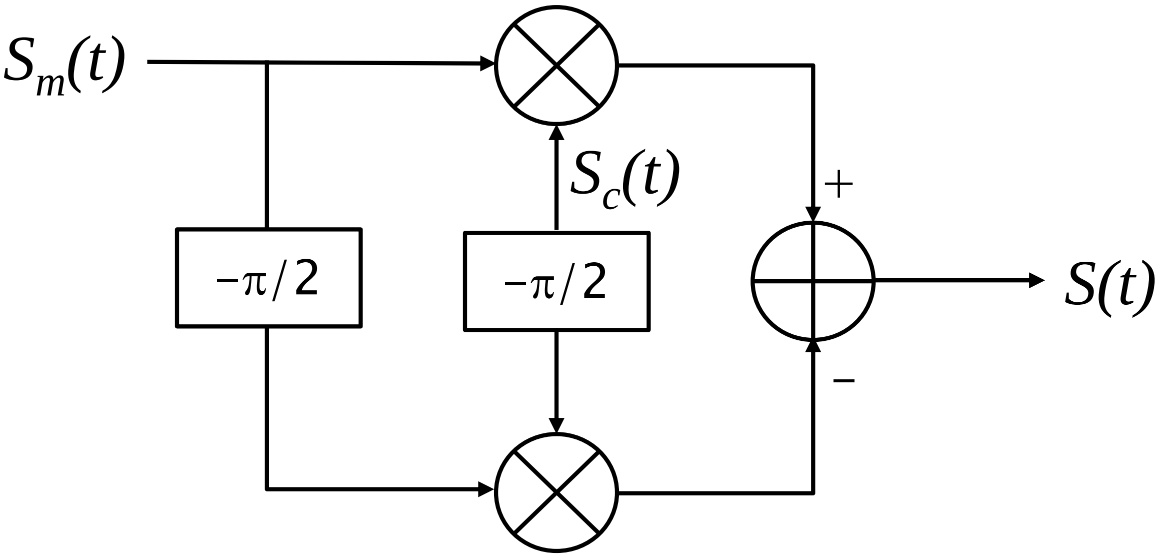
# Single-sideband modulation (SSB, or SSB-AM)

- Modulation scheme 1



# Single-sideband modulation (SSB, or SSB-AM)

- Modulation scheme 2



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# Phase and frequency modulation principles

- Emitted signal is $S(t) = A_c cos[2\pi f_c t+\varphi(t)]$

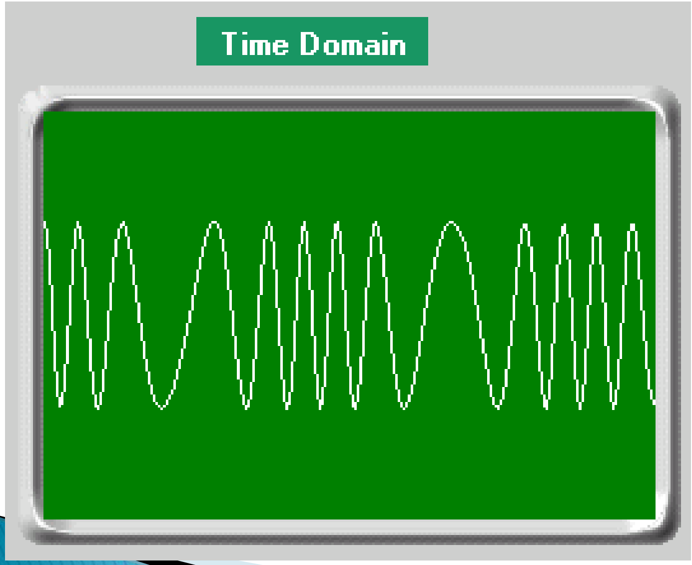
- Phase modulation:
  - $\varphi(t)$ is directly proportionnal to the modulanting signal $\varphi(t) = k\ S_m(t)$.
  - $k$ is the modulation sensitivity given in Hz.V$^{-1}$.
- Frequency modulation:
  - The variable part of the instant frequency is proportional to the modulanting signal
  - $\frac{d\varphi(t)}{dt} = kS_m(t)$

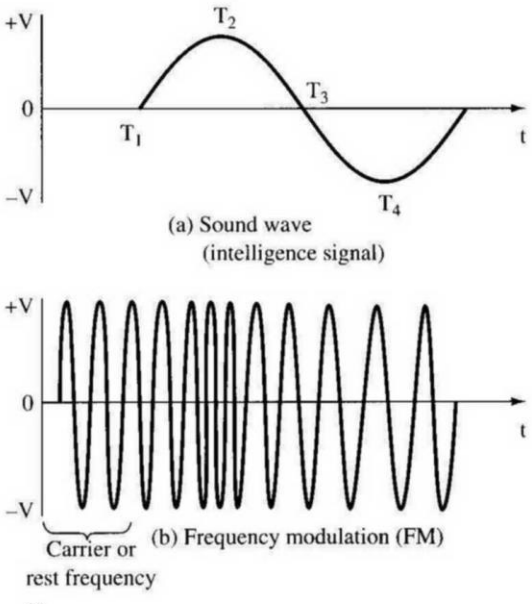
# Frequency Modulation of a sinusoid.

- Modulated signal:
  - $s(t) = A_c \cos[2\pi f_c t + \beta \sin(2\pi f_m t)]$.
- Instant frequency is $f_c + \beta f_m \cos(2\pi f_m t)$.
  - $\beta \sin(2\pi f_m t)$ = *phase deviation.*
  - $\beta$, is the *modulation index.*
  - $\beta f_m \cos(2\pi f_m t)$ = *frequency deviation.*
- Its maximum value or *peak frequency deviation* $\Delta f$ depends on the modulation index $\Delta f = \beta f_m$.

# Signal shape.

- If we don't know the modulant signal, we can't differenciate a frequency modulation from a phase one, by the modulated signal observation only.



# F.M. signal spectrum

- $S(t) = A_c \cos[2\pi f_c t + \beta \sin(2\pi f_m t)]$
  $= A_c[a(t) \cos(2\pi f_c t) - b(t) \sin(2\pi f_c t)].$

- **$a(t) = \cos(\beta \sin(2\pi f_m t)).$**
  - Mathematical decomposition:

  $a(t) = J_0(\beta) + 2\, J_2(\beta) \cos(2\pi\, 2f_m t) + \ldots$

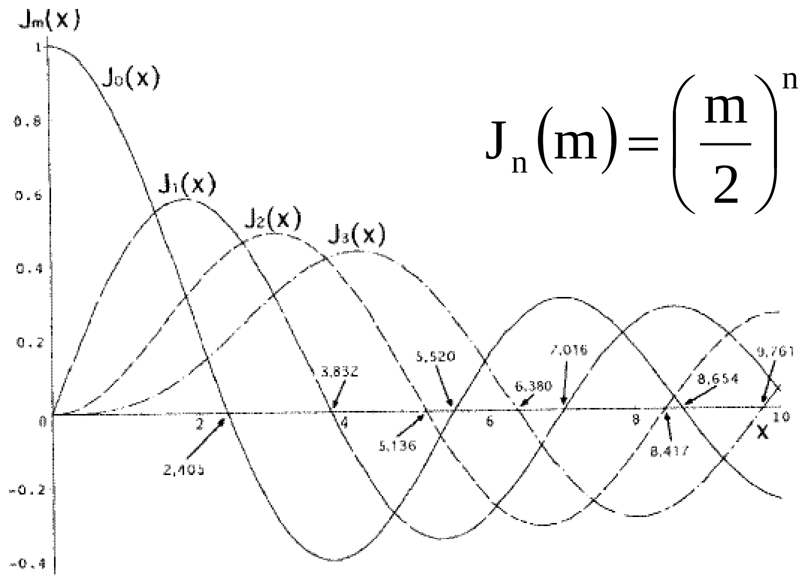
- **$b(t) = \sin(\beta \sin(2\pi f_m t)).$**
  - Mathematical decomposition:

  $b(t) = 2J_1(\beta)\sin(2\pi f_m t) + 2\, J_3(\beta) \sin(2\pi\, 3f_m t) + \ldots$

# Bessel functions of the first kind

$$S(t) = A_c\{J_0(\beta)\cos(2\pi f_c t)$$
$$+ J_1(\beta)\,[\cos(2\pi(f_c-f_m)t) - \cos(2\pi(f_c+f_m)t)]$$
$$+ J_2(\beta)\,[\cos(2\pi(f_c-2f_m)t) - \cos(2\pi(f_c+2f_m)t)]$$
$$+ \ldots + J_n(\beta)\,[\cos(2\pi(f_c-nf_m)t) - \cos(2\pi(f_c+nf_m)t)]$$

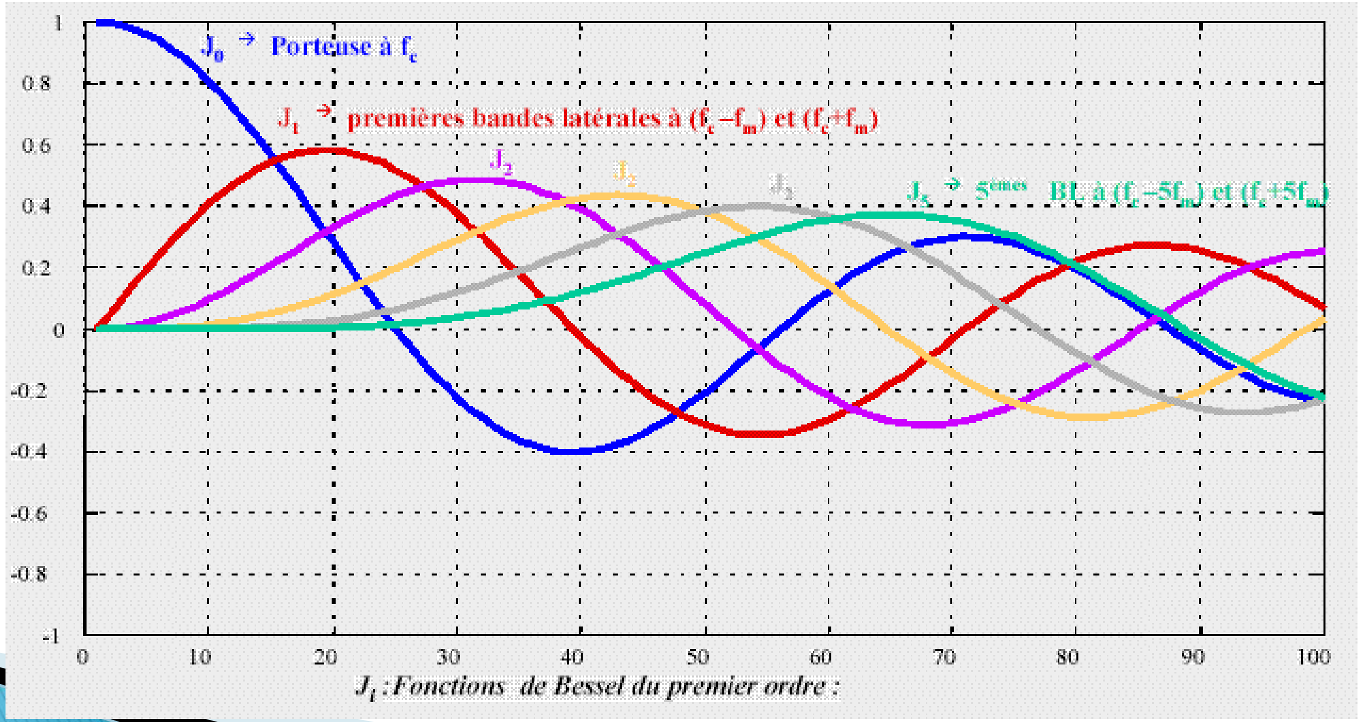
$$J_n(m) = \left(\frac{m}{2}\right)^n \sum_{0}^{\infty} \frac{(-1)^j \left(\frac{m}{2}\right)^{2j}}{j!\,(n+j)!}$$



# Bessel functionsof the first kind

$J_0(0) = 1$ and $J_n(0) = 0$ (no modulation).

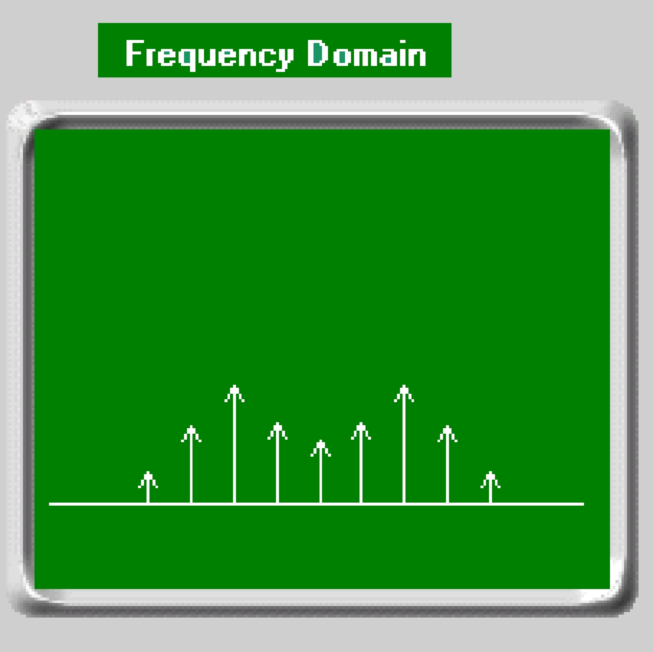
- When modulation index increases the modulated signal power is shared on lateral bands (less power for the carrier).



# Spectrum

- $f_c$ carrier with amplitude $|J_0(\beta)|$.
- Infinite lateral components $f_c \pm nf_m$ with amplitude $J_n(\beta)$.

$$s(t) = A\sum_{n=-\infty}^{+\infty} J_n(\beta)\cos\left(2\pi\left(f_c + nf_m\right)t\right)$$



# Carson's bandwidth rule

- The spectrum is infinite.
- But 98 % of the power is transmitted in the band

$$[f_c - (\beta+1)f_m ; f_c + (\beta+1)f_m].$$

- **Carson's bandwidth rule**

The transmission requires a bandwidth

$$B_c = 2(\beta+1)f_m = 2(\Delta f + f_m)$$ (*Carson bandwidth*).

# PM versus FM

| Modulating signal | Carrier |
| --- | --- |
| $S_m(t) = A_m cos(2\pi f_m t)$ | $S_c(t) = A_c cos(2\pi f_c t)$ |

- Phase modulation
- $\varphi(t) = k_{\varphi} S_m(t).$
  - Modulated signal

  $S_{\varphi}(t) = A_c \cos[2\pi f_c t + kA_m \cos(2\pi f_m t)]$

  $\beta_{\varphi} = k_{\varphi} A_m.$

  $B_{c\_\varphi} = 2(\beta_{\varphi} + 1) f_m \approx 2 k_{\varphi} A_m f_m.$
  - The spectrum occupancy is related to the frequency of the modulating signal

- Frequency modulation
  - The index modulation is

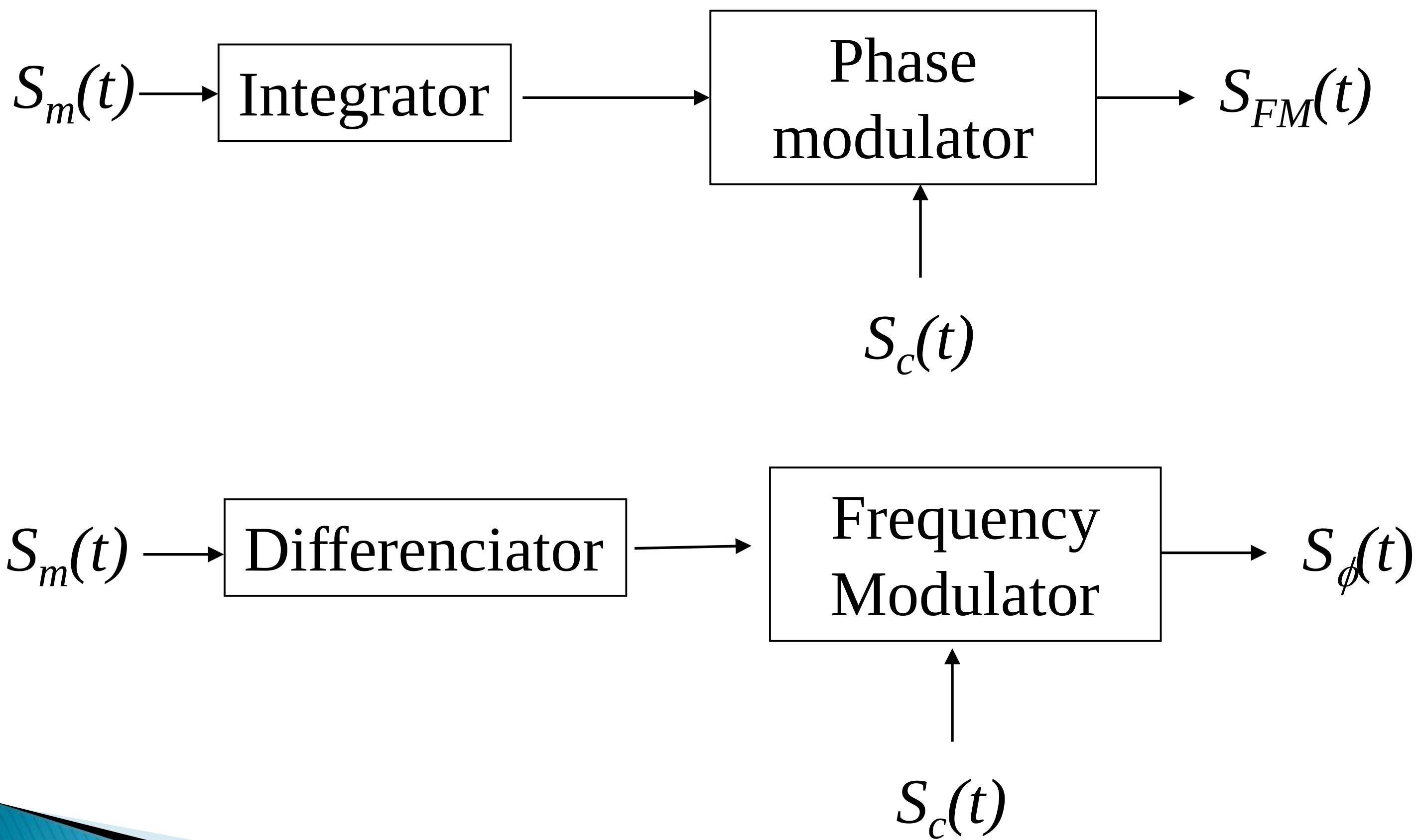
  $$\beta_{FM} = \frac{k_{FM} A_m}{2\pi f_m}$$

  - Spectrum occupacy

  $$B_{c\_FM} = \frac{k_{FM} A_m}{\pi}$$

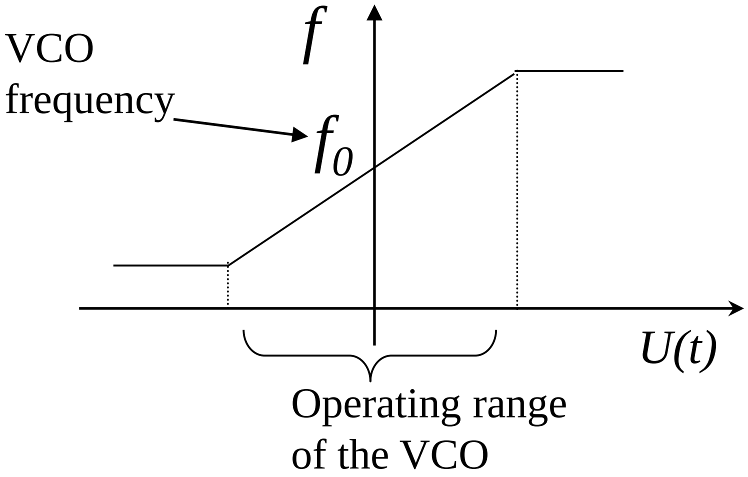
  - Is independent of the frequency of the modulating signal

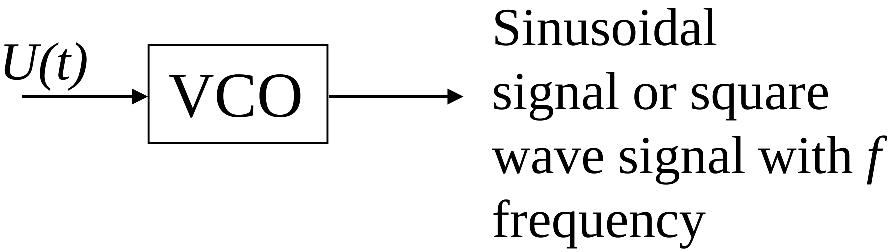
# PM versus FM


$S_m(t)$
Integrator
Phase modulator
$S_{FM}(t)$
$S_c(t)$
$S_m(t)$
Differenciator
Frequency Modulator
$S_\phi(t)$
$S_c(t)$

# FM Modulation

- Voltage Controlled Oscillator (VCO)
  - The VCO is a component that delivers a frequency modulated signal, the input is a control voltage U(t).

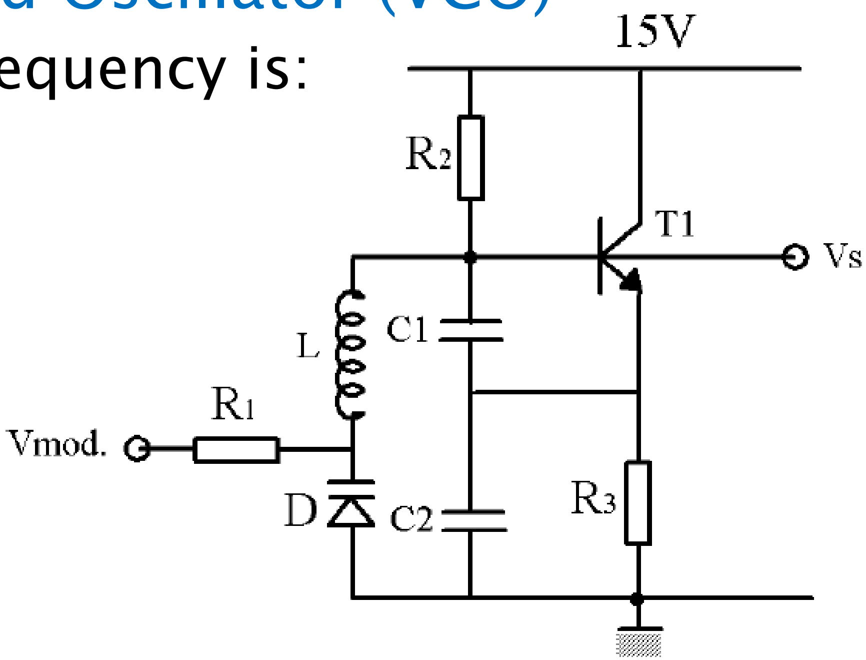


# FM Modulation

- Voltage Controlled Oscillator (VCO)
  - The oscillation frequency is:

$$f_c = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{LC}}$$

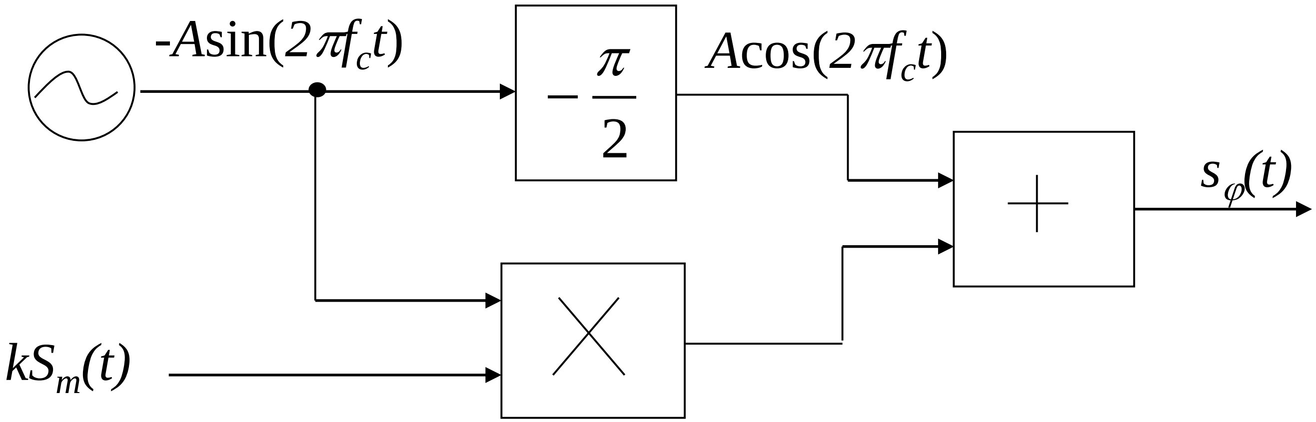



  - Made, for example, with a Colpitts type oscillator
  - The diode D is a varicap diode which has a variable capacity depending on the applied reverse voltage.

# Armstrong Method

- Phase Modulator
- $S_\varphi(t) = A_c\cos[2\pi f_c t + k\, S_m(t)]$.
  - If $k\, S_m(t) \ll 1$,

    $S_\varphi(t) = A_c\cos(2\pi f_c t) - k\, S_m(t) A_c \sin(2\pi f_c t)$

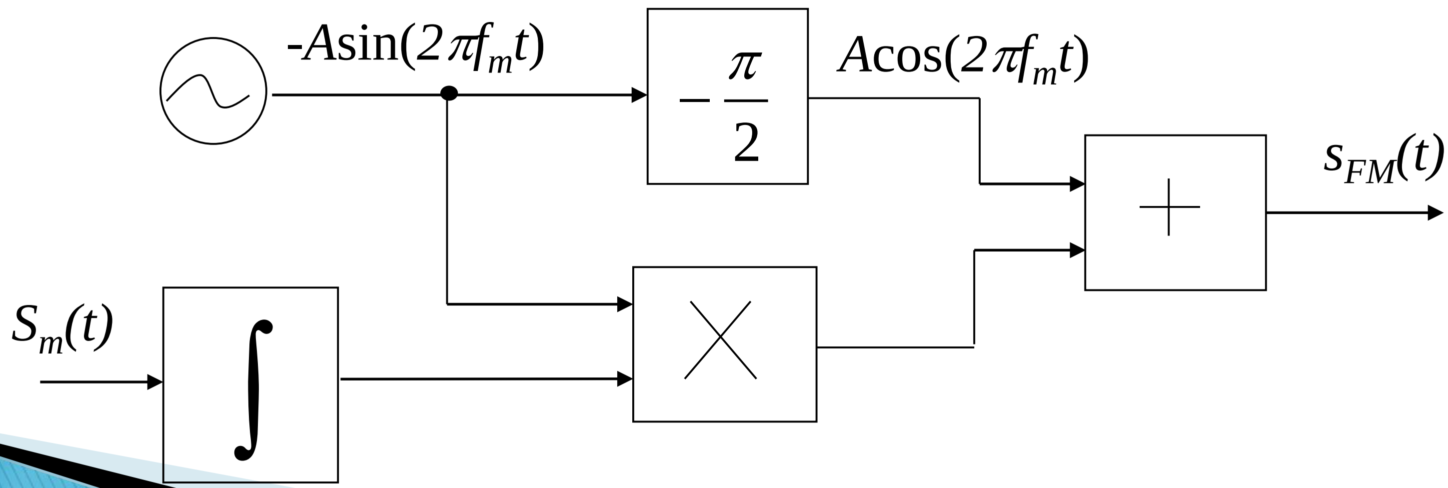


# Armstrong Method

- Frequency Modulator

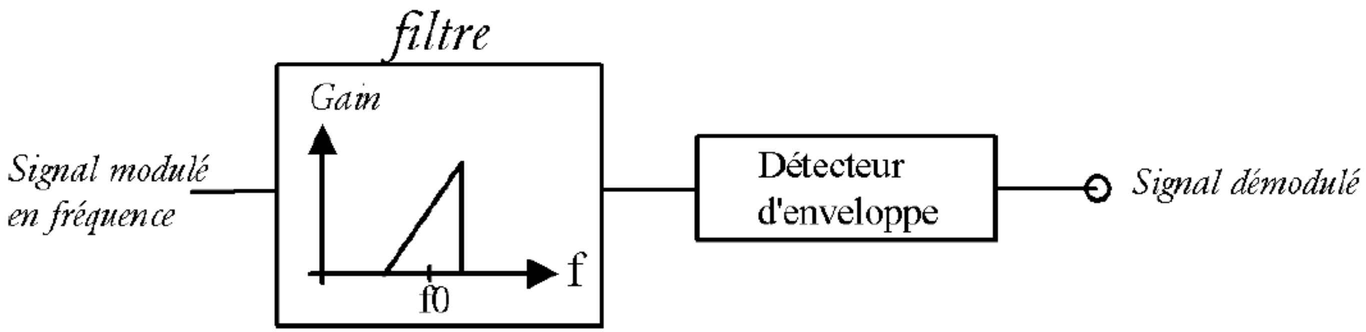
$$s_{FM}(t) = A\cos\left[2\pi f_c t + 2\pi\Delta f \int_0^t S_m(\tau)d\tau\right]$$

$$\text{if } 2\pi\Delta f \int_0^t S_m(\tau)d\tau << 1,$$



# Demodulation

- Frequency discriminator :
  - Transform FM in AM



# Outline

- Introduction
- Transmission system components
- Modulation principle
- Analog modulations
  - Amplitude modulations
  - Frequency and phase modulations
- Digital modulations
- Main transceiver architectures

# Outline

- Introduction
- Transmission system components
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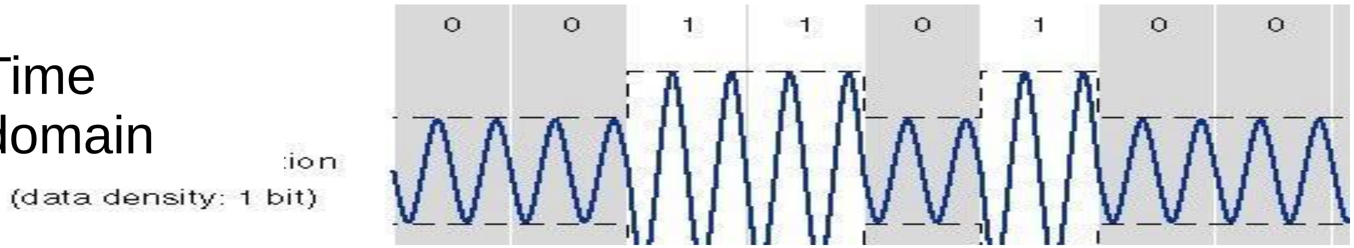
  - Amplitude modulations (ASK)
  - Frequency modulations (FSK)
  - Phase modulations (PSK)
- Main transceiver architectures

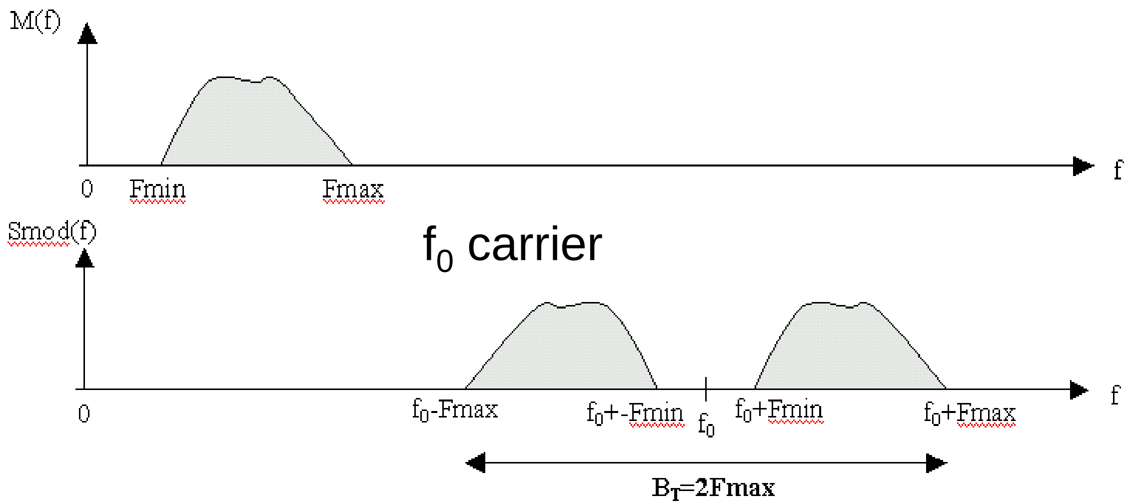
# ASK – Amplitude Shift Keying

- 2 amplitudes for 0 and 1

Time domain




Frequency domain

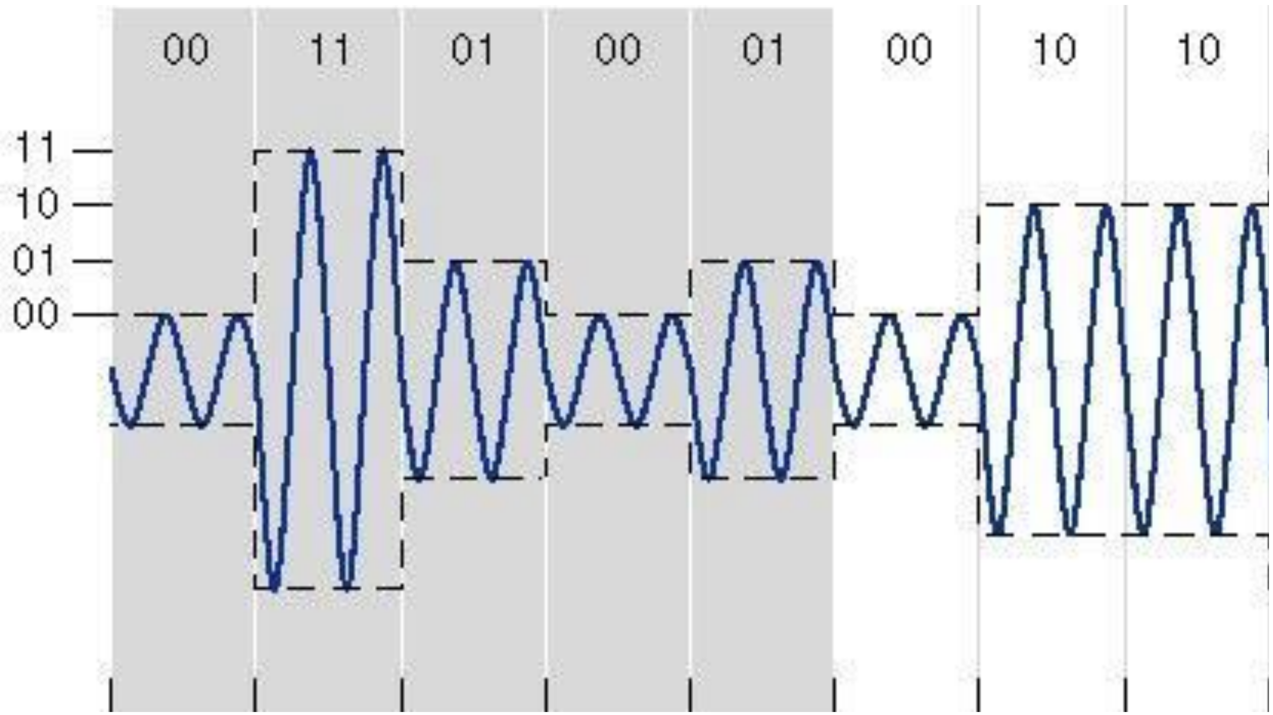



- Other method: On Off Keying (OOK)
  - 0 -> no signal
  - 1-> carrier

# ASK – Amplitude Shift Keying

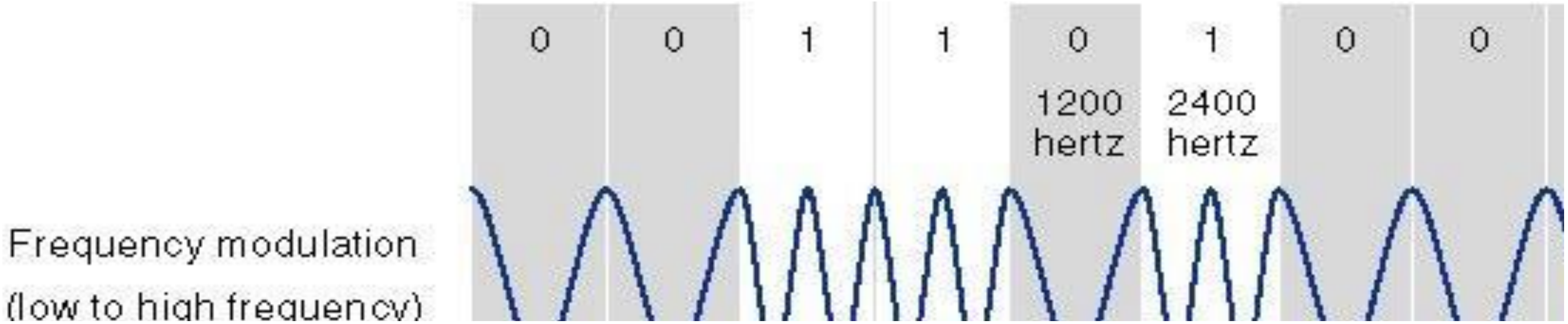
- More efficient: send several bits at the same time

Amplitude modulation
(data density: 2 bits)



# Frequency Shift Keying – FSK

- 1 –> $f_{1\ carrier}$
- 0 –> $f_{2\ carrier}$



# Frequency Shift Keying – FSK

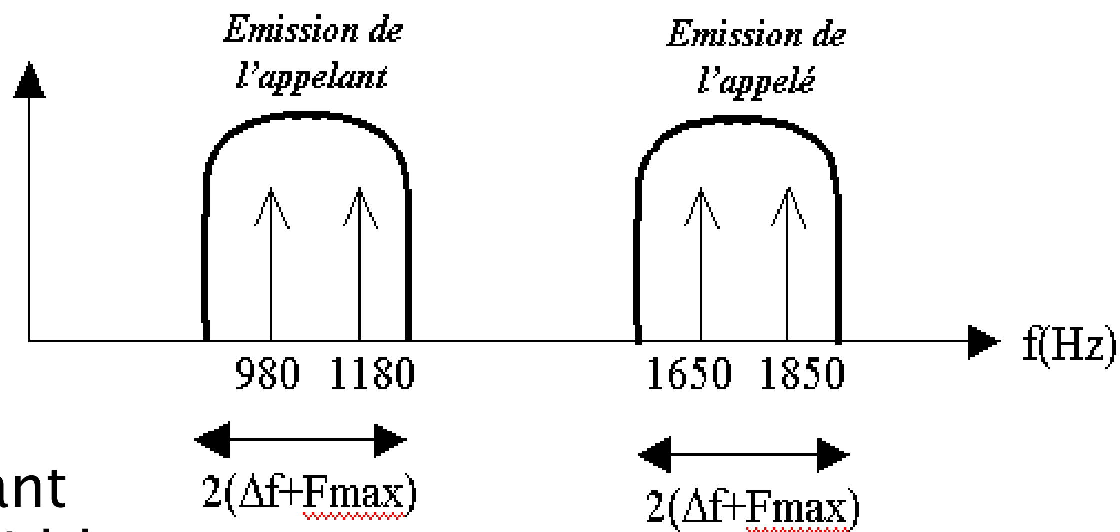
- Example

**channel 1 :**

- « 1 » → $f_1$= 980Hz
- « 0 » → $f_2$= 1180Hz

**channel 2 :**

- « 1 » → $f_1$= 1650Hz
- « 0 » → $f_2$= 1850Hz

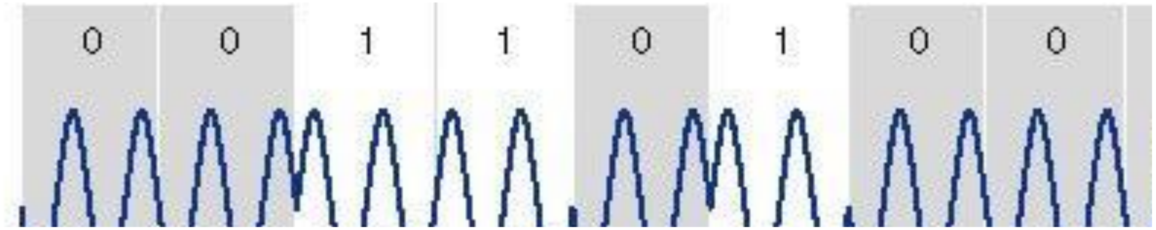



- + noise resistant
- – wider bandwidth

# Phase Shift Keying - PSK

- 1 -> $\varphi_1$
- 0 -> $\varphi_2$
- Example: BPSK – PSK with 2 states or levels
  - 0 -> in phase with the carrier
  - 1-> 180° shift

Phase modulation



# Phase Shift Keying - PSK

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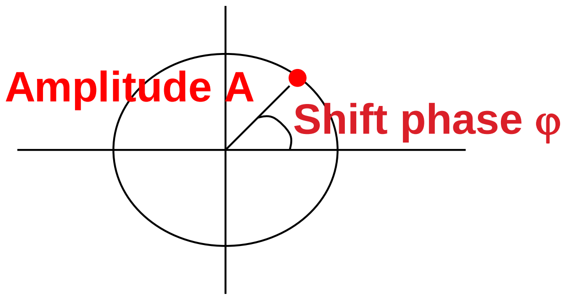
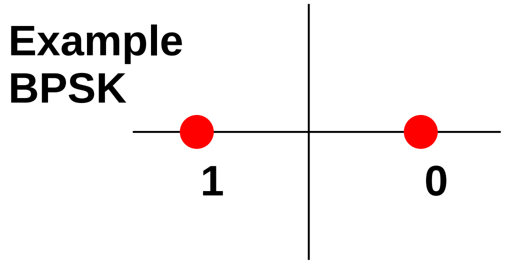


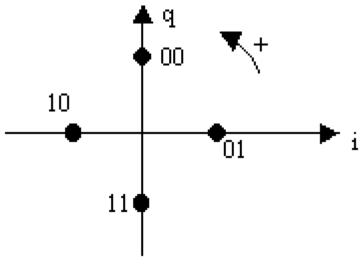




**Trigonometrical graph or constellation**

# Phase Shift Keying - PSK

- 4-PSK

| Information | Carrier phase |
|---|---|
| 01 | 0 |
| 00 | 90 |
| 10 | 180 |
| 11 | 270 |




**Constellation**

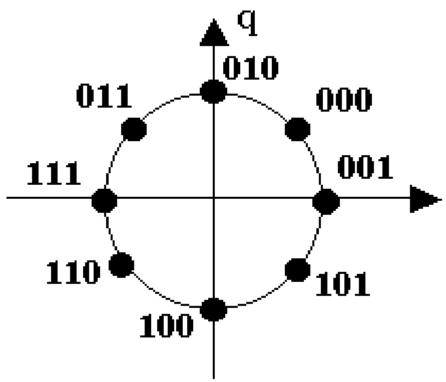
- At each point of the constellation, we associate a 2-bit binary word.

# Phase Shift Keying - PSK

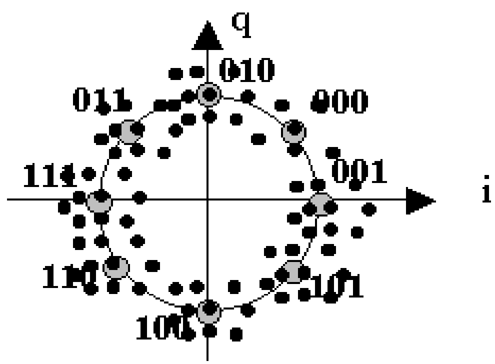
- DPSK (Differential Phase Shift Keying)
  - The phase change is relative to the previous state of the carrier
  - Good synchronization between transmitter and receiver => periodic sending of sequences of 1 and 0

# Modulation speed

- The higher the number of states, the higher the speed of data transmission.
- But: Influence of noise => High error probability




Without noise

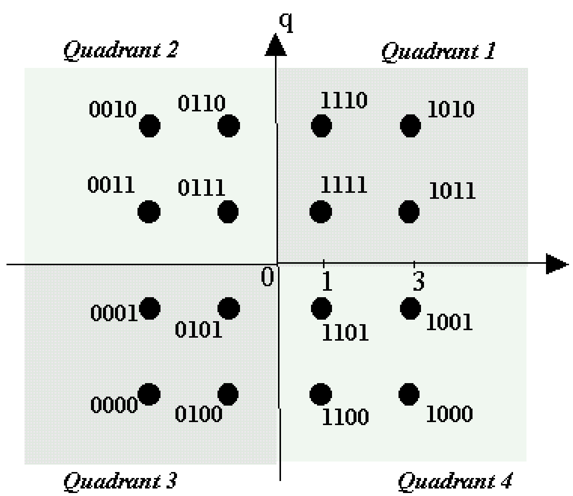



With noise

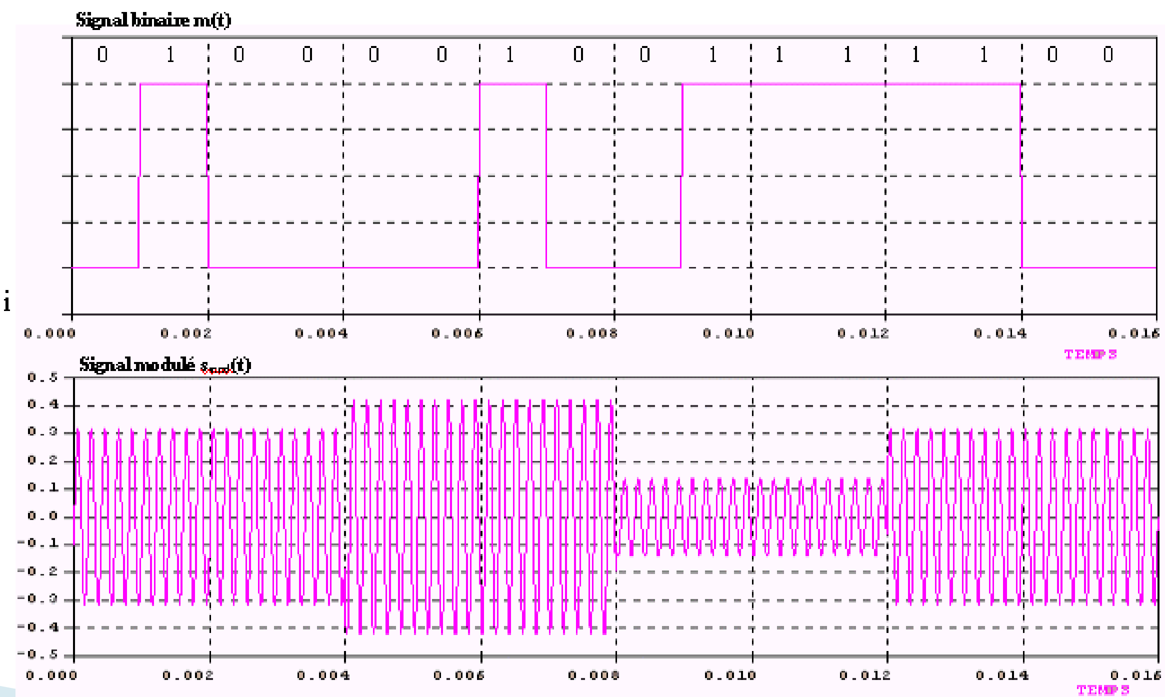
- Modulation speed in Baud: emitted symbols/second
- Binary rate: emitted bits/second

# Other Modulations

- Combination of amplitude and phase modulations M–QAM = of M phase states and amplitude.
- In general, M = 2n: each symbol gives a code for
- n = log2(M) bits.




Example: 16-QAM



# Digital Modulations Applications

| Modulation format | Application |
|---|---|
| MSK, GMSK | GSM, CDPD |
| BPSK | Deep space telemetry, cable modems |
| QPSK, $\pi/4$ DQPSK | Satellite, CDMA, NADC, TETRA, PHS, PDC, LMDS, DVB-S, cable (return path), cable modems, TFTS |
| OQPSK | CDMA, satellite |
| FSK, GFSK | DECT, paging, RAM mobile data, AMPS, CT2, ERMES, land mobile, public safety |
| 8, 16 VSB | North American digital TV (ATV), broadcast, cable |
| 8PSK | Satellite, aircraft, telemetry pilots for monitoring broadband video systems |
| 16 QAM | Microwave digital radio, modems, DVB-C, DVB-T |
| 32 QAM | Terrestrial microwave, DVB-T |
| 64 QAM | DVB-C, modems, broadband set top boxes, MMDS |
| 256 QAM | Modems, DVB-C (Europe), Digital Video (US) |

# Digital Modulations Applications

| Modulation format | Theoretical bandwidth efficiency limits |
|---|---|
| MSK | 1 bit/second/Hz |
| BPSK | 1 bit/second/Hz |
| QPSK | 2 bits/second/Hz |
| 8PSK | 3 bits/second/Hz |
| 16 QAM | 4 bits/second/Hz |
| 32 QAM | 5 bits/second/Hz |
| 64 QAM | 6 bits/second/Hz |
| 256 QAM | 8 bits/second/Hz |

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# Definitions for RF systems

- BER and SNR
  - BER for assess the system performance.
    - Wrong received bits / transmitted bits
  - SNR for assess the system performance.
    - Signal to Noise Ratio

  - We can deduce the $SNR_{out}$ needed from the BER.

$$\frac{C}{N} = SNR_{out} = \frac{E_b}{N_0}\frac{R}{B}$$

# Definitions for RF systems

- BER and SNR
  - We can deduce the $SNR_{out}$ needed from the BER.

$$\frac{C}{N} = SNR_{out} = \frac{E_b}{N_0}\frac{R}{B}$$

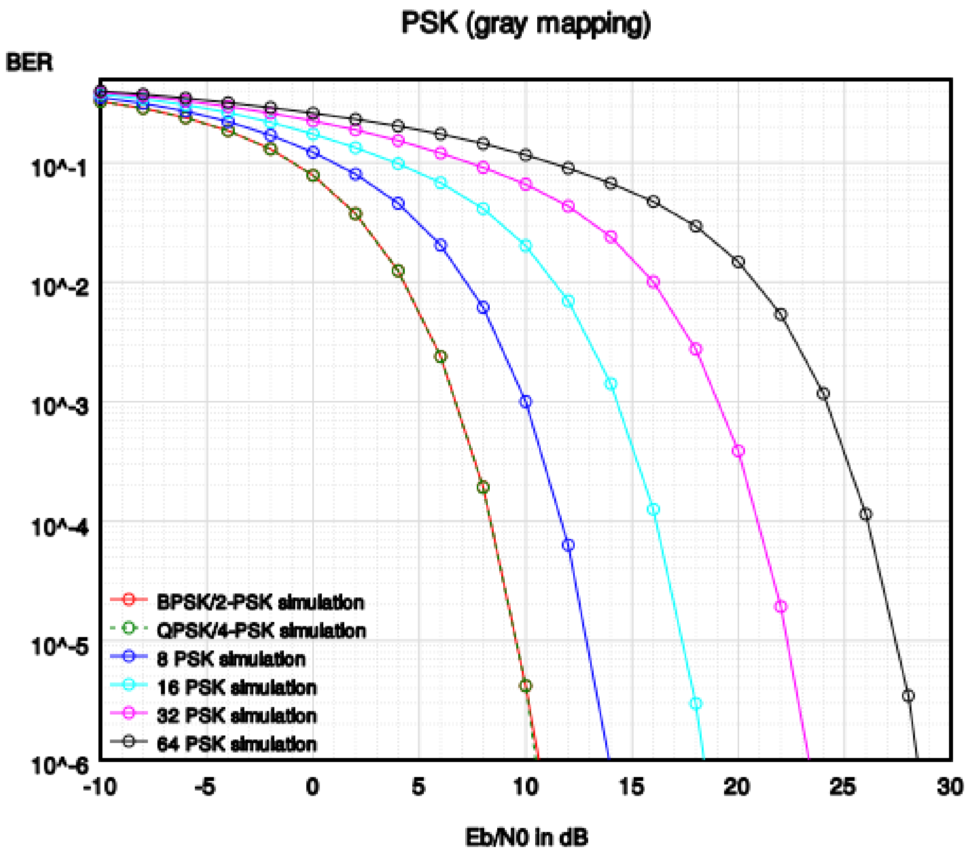
$$P_{eQPSK} = Q\left(\sqrt{2\frac{E_b}{N_0}}\right)$$

$$Q(x) = \frac{1}{2} erfc\left(\frac{x}{\sqrt{2}}\right)$$

$E_b$ is the energy per bit
$N_0$ is a noise AWGN

# Definitions for RF systems

- BER and SNR



# Definitions for RF systems

- Noise Figure
  - How much the system deteriorates the SNR

$$NF = \frac{SNR_{in}}{SNR_{out}}$$

  - $SNR_{in}$ depends on input signal power
  - $SNR_{out}$ depends on the BER

$$SNR_{in} = \frac{S}{N_t}$$

$$N_t = kBT$$

$$N_t[W] = kBT$$

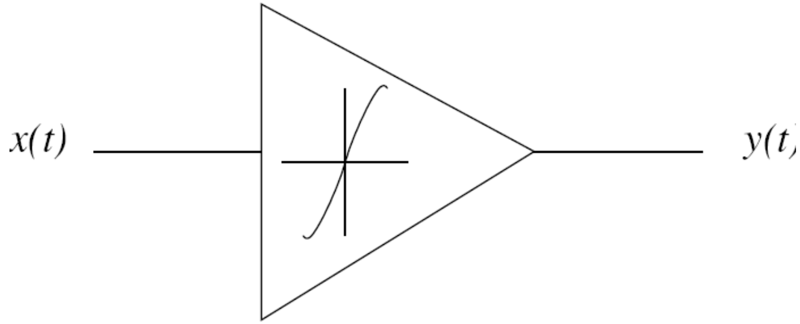
$$\text{with } k = 1{,}38.10^{-23}\ J/K$$

$$T[K] = 273 + T[°C]$$

k is the Boltzmann constant
T is the temperature in Kelvin

# Definitions for RF systems

- Linearity



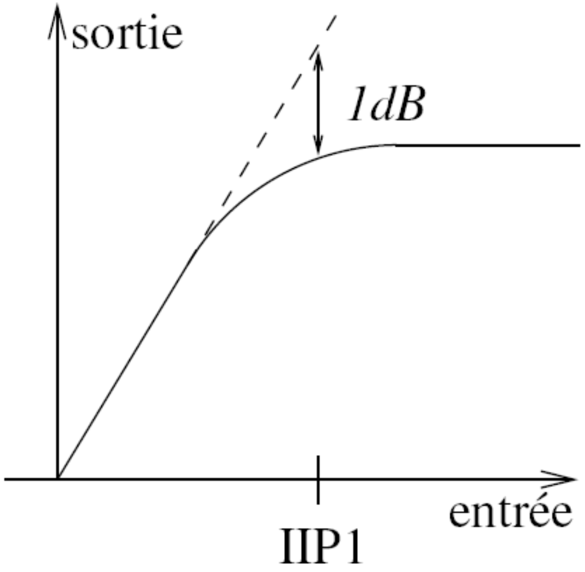

$$y(t) = \alpha_1 x(t) + \alpha_2 x^2(t) + \alpha_3 x^3(t) + \ldots$$

- The non-linearity generates distorsions:
  - Gain compression
  - Harmonic ditorsion
  - Intermodulation

# Definitions for RF systems

- Linearity
  - Gain compression

$$IIP1 = 20\log A_{IIP1}$$



# Definitions for RF systems

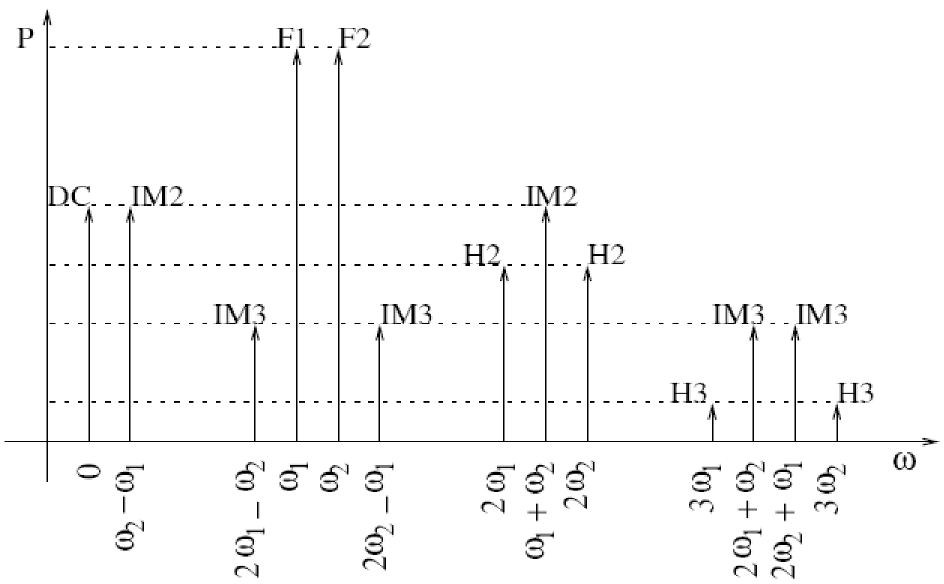
- Linearity
  - Harmonic ditorsion

$$y(t)=\alpha_1 x(t)+\alpha_2 x^2(t)+\alpha_3 x^3(t)+\ldots$$

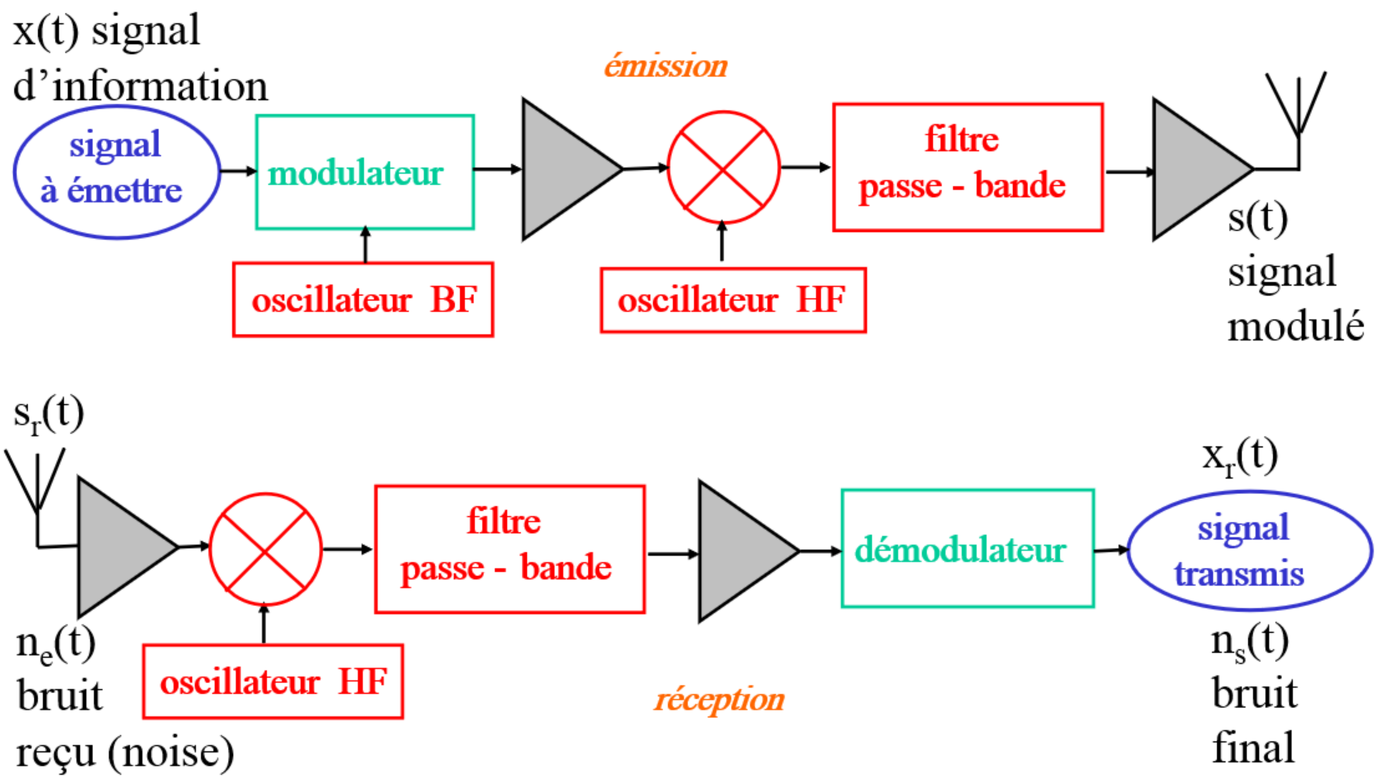
$$HD_n=\frac{\alpha_n}{\alpha_1}$$

$$THD=\sqrt{HD_2^2+HD_3^2+\ldots}$$

  - Intermodulation

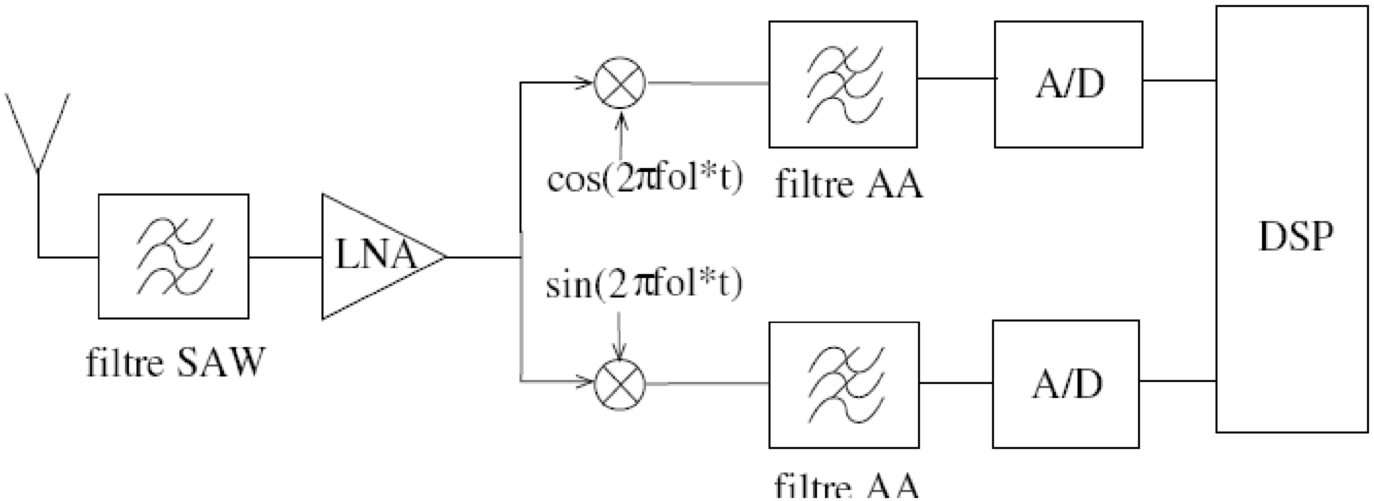


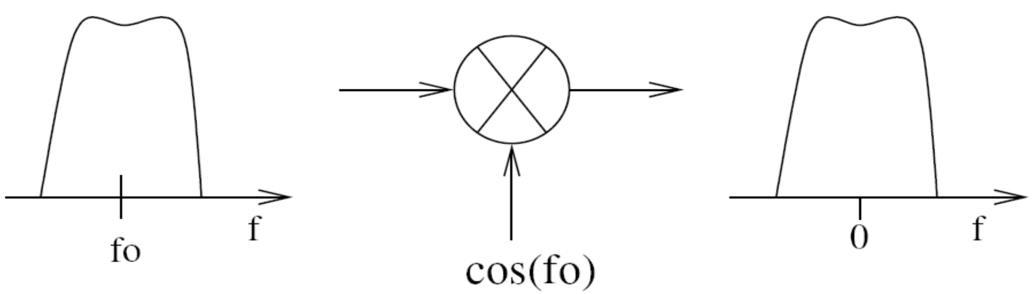
# Receiver – General Scheme




Efficacité vis-à-vis du bruit à la démodulation $\eta = \dfrac{(\text{Puissance } x_r)/(\text{Puissance } n_s)}{(\text{Puissance } s_r)/(\text{Puissance } n_e)}$

# Homodyne Receiver



# Homodyne Receiver